Assessment of Surface Water and Groundwater Interchange within the Muck Creek Watershed Pierce County

December 2001

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Cover photograph: Muck Creek at Roy, September 28, 2000

Assessment of Surface Water and Groundwater Interchange within the Muck Creek Watershed Pierce County

by
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Glossary

Acre foot – The quantity of water required to cover one acre of land to a depth of one foot. One acre foot is equal to 43,560 cubic feet or 325,829 gallons of water.

Annual 7-day low flow – The lowest mean streamflow for seven consecutive days in a water year (or calendar year). Values typically presented in cubic feet per second (ft3/sec).

Cubic foot per second (ft3/sec) – The rate of discharge representing a volume of one cubic foot (of water) passing a given point during one second. The value 1 ft3/sec is equivalent to 7.48 gallons per second (gps) or 448.8 gallons per minute (gpm).

Discharge area – An area in which there are upward components of hydraulic head. Groundwater flows toward land surface in a discharge area and may emerge by evaporation or transpiration, or as discharge to a spring, seep, or stream.

Hydraulic head (head) – The pressure exerted by a water mass at any given point. Total head is the sum of elevation head, pressure head, and velocity head.

Hydraulic conductivity – A coefficient that describes the rate of water movement through a permeable medium. Hydraulic conductivity is expressed as the volume of water at the prevailing kinematic viscosity, that will move through a unit area of material at right angles to the flow direction, per unit hydraulic gradient, per unit time.

Intermittent stream – A stream that ceases to flow during some portion of the year, usually during the summer.

Outwash (advance or recessional) – Stratified detritus (chiefly sand and gravel) removed or "washed out" from the glacier by meltwater streams, and deposited in front of or beyond the terminal moraine or along the margin of an active glacier. Outwash deposited during glacial advance is called advance outwash, while outwash deposited during glacial retreat is referred to as recessional outwash (Gary et al., 1974).

Perennial stream – A stream that flows year round.

Piezometer – A nonpumping well, generally of small diameter, which is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen or perforations through which water can enter (Fetter, 1980).

Specific capacity – A measure of a well's production capacity defined as the yield per unit drawdown. Specific capacity is usually expressed in units of gallons per minute per foot of drawdown (gmp/ft).

Specific conductance – A measure of a water's ability to conduct electricity. In this report specific conductance is reported in units of µs/cm @ 25°C.

Till – A heterogeneous mixture (generally unsorted, unstratified, and unconsolidated) of clay, sand, gravel, and boulders deposited directly by and underneath a glacier without subsequent reworking by glacial meltwater.

Water year – A term used to describe the 12-month period starting on October 1 and ending on September 30. A water year is designated by the calendar year in which it ends. Thus, the year ending on September 30, 2000 is called the "2000 water year".

Conversion Factors and Vertical Datum

Multiply	By	To Obtain
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
square ft (ft2)	0.0929	square meter
acre	0.4047	hectare
	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot (ft3)	0.02832	cubic meter
cubic foot per second per mile (ft3/sec/mi)	0.0176	cubic meter per second per kilometer
cubic foot per second per square mile (ft3/sec/mi2)	0.01093	cubic meter per second per square kilometer
cubic foot (ft3)	28.32	liter
mile (mi)	1.609	kilometer
square mile (mi2)	2.59	square kilometer
gallon (gal)	3.785	liter
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Temperature

To convert degrees Celsius (°C) to degrees Fahrenheit (°F), use the following equation:
°F= 9/5°C + 32.

To convert degrees Fahrenheit (°F) to degrees Celsius (°C), use the following equation:
°C= 5/9(°F-32).

Sea Level

In this report, sea level refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

Altitude

In this report, altitude is measured in feet above mean sea level

Abstract

The Muck Creek watershed in southwestern Pierce County supports native runs of chum, coho, and steelhead salmon, as well as resident and sea-run cutthroat trout. Over time, human activities and land-use changes have reduced the quantity and quality of instream habitat within the watershed. Despite the initiation of several stream restoration projects, potentially valuable habitat in the upper watershed remains inaccessible to salmon due to intermittent stream conditions affecting the central watershed. This study was undertaken to evaluate the potential cause(s) of intermittent flow conditions within the watershed, and to provide a general overview of the hydrogeologic setting which gives rise to these conditions.

The study area hydrogeologic framework was subdivided into nine hydrogeologic units (five aquifers and four confining units) using data from 171 inventoried wells and springs. Groundwater recharge from precipitation was estimated using regression methods developed by Woodward et al. (1995). Water levels from inventoried wells were used to prepare a generalized water-level altitude map and to evaluate seasonal and long-term groundwater fluctuations. Mini-instream piezometers were used to define the vertical hydraulic gradient and direction of water flow between streams and groundwater at specific locations, while stream seepage evaluations were used to quantify gains and losses across larger stream reaches.

Results indicate that groundwater recharge from precipitation averages approximately 21 inches per year, or 108,000 acre feet, and ranges from 17 to 28 inches across the study area. Additional recharge through losing stream reaches was estimated at approximately 22,000 acre feet, and accounted for approximately 17 percent of total recharge. Groundwater movement is generally toward the west and northwest from upland recharge areas in the eastern watershed toward natural points of discharge along area streams and the Nisqually River.

Direct groundwater discharge to streams is largely restricted to the perennial reaches of upper and lower Muck Creek, central South Creek, and upper Lacamas Creek where measured streamflow gains ranged from approximately 0.1 to 1.3 ft3/sec per river mile. Seepage losses were greatest in central Muck Creek and lower South Creek where these streams are perched above the regional water table and naturally lose water as they traverse highly permeable deposits of coarse sand and gravel.

Acknowledgements

Numerous people contributed time and effort to this study:

- Jeanette Dorner and Peter Moulton are the study's initiating advocates and helped to define and guide its direction.
- James Crawford (CH2mHill Inc.) assisted during the June 2000 seepage evaluation and provided streamflow records for two Muck Creek gages maintained by CH2mHill and Pierce County. The gages were installed in support of the basin Plan being developed for Muck Creek by Pierce County Public Works and Utilities.
- Many residents of the watershed graciously provided access to their wells and property which enabled us to collect the data this study drew upon.
- Washington State Department of Ecology staff who contributed to this study include:
    - Paul Anderson, Nigel Blakley, Brandee Era, Robert Garrigues, Katina Kapantais, Charles Pitz, and Morgan Roose assisted with data collection.
    - Richard Kim provided Geographic Information System support
    - Robert Garrigues, Charles Pitz, and Dale Norton provided comments on the draft report.
    - Steve Barrett provided software and Internet support.
    - Joan LeTourneau formatted and edited the final report.

Introduction

This report describes the findings of a study initiated by the Washington State Department of Ecology (Ecology) in 1999, to assess the interchange that occurs between streams and groundwater within the Muck Creek watershed of southwestern Pierce County, Washington (Figure 1). Muck Creek, like many streams in the Puget Sound lowland, supports important runs of native salmon as well as resident and sea-run-cutthroat trout (Walter, 1999). Human population growth and associated land-use changes over the years have directly and indirectly impacted the quantity and quality of habitat available to spawning and rearing salmon.

State fisheries managers formally recognized the impact of "acute low water conditions" on Muck Creek's salmon populations in 1948, when the directors of Washington's Fisheries and Game Departments jointly requested that the Department of Conservation and Development (now Ecology) deny applications for consumptive water diversions from Muck and Lacamas creeks (Fisheries, 1948). This informal "closure" was subsequently adopted and codified in Chapter 173-511 WAC (Instream Resources Protection Program – Nisqually River Basin).

While the instream resources protection program theoretically shielded Muck Creek from additional out-of-stream diversions, it offered little protection against development and mounting land-use changes. Muck Creek was dammed in 1967 and again in 1976 to form Chambers Lake and Johnson Lake (Figure 1). Muck Creek and its major tributaries, Lacamas Creek and South Creek, were dredged and channeled at various locations, in the past, to contain flow and alleviate winter flooding problems (CH2mHill, 2000). Rampant growth of exotic reed canary grass severely impacts salmon passage and spawning in many areas of the watershed.

In recent years government, tribal, and citizen-based restoration and enhancement efforts have been undertaken to counter this progressive loss of instream habitat (Walter, 1999; Dorner, 1999; CH2mHill, 2000). Despite such efforts, potentially valuable habitat within the upper watershed remains inaccessible to salmon due to intermittent streamflow conditions affecting the central watershed. This study was initiated in support of these restoration efforts and was designed to develop a better understanding of the distribution, timing, and cause(s) of intermittent flow conditions within the central watershed.

Study Purpose and Scope

The purpose of this study is to better define the hydraulic interaction between streams and groundwater within the Muck Creek watershed. Descriptions of the timing, location, and magnitude of surface water and groundwater interchange are provided, along with a general discussion of the hydrogeologic framework within which this interchange occurs. The study results will be used by state, county, and local resource management agencies involved in water allocation, land-use planning, and salmon enhancement efforts within the watershed.

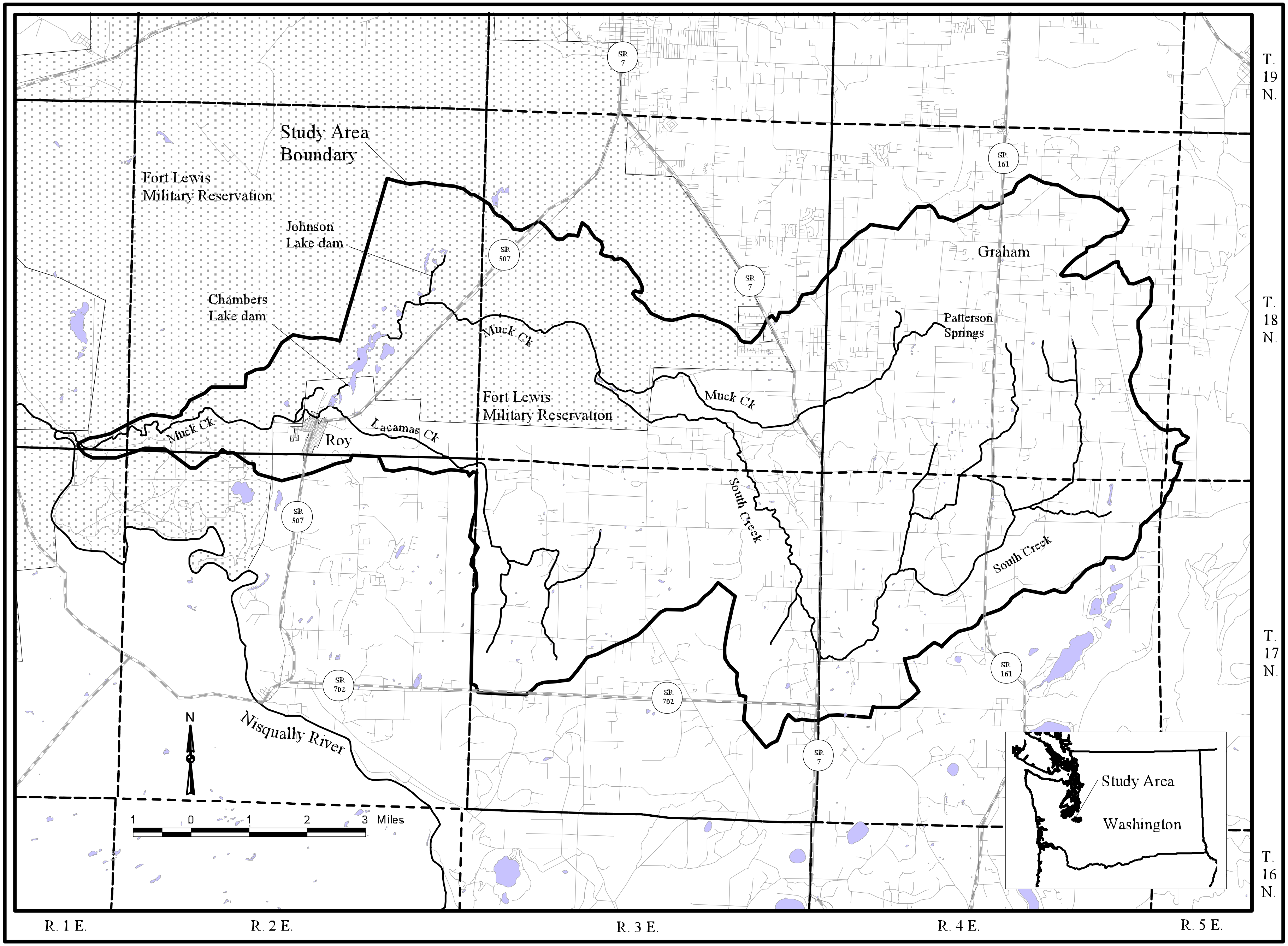

Figure 1 – Location of study area

The major objectives of this study were to:

- Evaluate and describe the timing, volume, and distribution of surface water and groundwater interchange within the study area.
- Provide a better understanding of the hydrogeologic framework within which this interaction occurs.
- Determine if area streamflows or groundwater levels have been measurably impacted by past land-use changes within the watershed.

Study Area Description

The Muck Creek watershed encompasses approximately 96 square miles within southwestern Pierce County (Figure 1). Roughly 25 percent of the watershed lies within the Fort Lewis Military Reservation (Fort Lewis). This portion of the watershed contains few permanent structures and consists of broad grass-covered prairies, oak savanna, and coniferous woodlands. It is generally unused except during periodic military training maneuvers. The remainder of the watershed, which includes the communities of Roy and Graham, consists of mixed woodlands, agricultural fields, and low-to-moderate density residential development.

The study area is drained by three principal streams: Muck Creek, South Creek, and Lacamas Creek.

Muck Creek originates at Patterson Springs, approximately two miles southwest of Graham and flows generally southwest along the southern margin of the Muck Creek channel, an erosional trough that formed as the vashon glacier retreated. Approximately four miles below Patterson Springs, Muck Creek trends west and flows across the eastern Fort Lewis prairie complex where it is joined by South Creek.

South Creek drains the till-covered uplands south and west of Graham. Its headwaters consist of numerous natural channels and roadside ditches which collect surface runoff and carry it toward the south-southwest, on a generally parallel course with Muck Creek. Near its midpoint South Creek turns sharply to the northwest and drops to the Fort Lewis prairie where it joins with Muck Creek. The combined flow of Muck Creek and South Creek is carried west across the prairie in a largely gravel-bottomed channel.

West of Highway 507, Muck Creek flows southward through a series of interconnected wetlands and lakes where it is joined by Lacamas Creek just north of the town of Roy. From Roy, Muck Creek flows generally west, for approximately four miles, across the western prairies of Fort Lewis before dropping through a narrow ravine and discharging into the Nisqually River.

The Muck Creek watershed, like much of the Puget Sound lowland, was shaped by repeated glacial advances and retreats over the past few million years. Deposits from the most recent glaciation blanket the area and exert the greatest influence on the watershed hydrology. The study area contains two distinct physiographic regions: an expansive till-covered upland to the south, and low-lying, outwash-covered prairies to the north and west. The till-covered uplands, which comprise most of the South Creek drainage and a portion of the Lacamas Creek drainage, lie at altitudes of 500 to 960 feet. The northern and western outwash prairies lie at altitudes between 300 and 500 feet, and are contained mostly within the Muck Creek drainage.

Archeological evidence suggests that ancestors of the present day Nisqually Indians inhabited the Nisqually River watershed at least 5,000 years ago (Wilkinson, 1999) and resided in several villages near Muck Creek. In addition to abundant salmon, this location provided easy access to the Nisqually River tidelands where shellfish were plentiful, and to the upland prairies of Muck Creek where herbs and other native plants were harvested.

European settlement of Muck Creek began in the 1840s when the British Hudson's Bay Company established an agricultural station within the watershed's open prairies. There, workers grazed cattle and sheep and cultivated potatoes, wheat, and barley to support company activities at nearby Fort Nisqually. Passage of the Donation Land Claim Act of 1850 accelerated the influx of Europeans, as settlers moved west and staked homesteads on the Muck Creek prairie and elsewhere. With the establishment of Fort Lewis (previously Camp Lewis) in 1917, settlers whose homesteads were contained within the newly designated military reservation were required to vacate their property.

Well and Spring-Numbering System

The locations of all wells and springs referenced in this report are described using the township, range, section, and quarter-quarter section convention. Range designations include an "E" and township designations include an "N," to indicate the well or spring lies east and north of the Willamette meridian and baseline, respectively. Quarter-quarter sections are represented by a single capital letter. Spring sites are differentiated from well sites by placing an "-S" after the quarter-quarter designation. If more than one well or spring is inventoried within a quarter-quarter section, a sequence number is added after the quarter-quarter designation to assure uniqueness. For example, the first inventoried well located in the southeast quarter of the northeast quarter of Section 24, Township 17N, Range 03E, is recorded as 17N/03E-24H01, the second well as 24H02, and so on (Figure 2).

This site location and numbering convention has been used for many years by Ecology, the U.S. Geological Survey (USGS), and others, and sometimes results in numbering conflicts between reports or agencies. Numerous wells previously inventoried by the USGS are referenced in this report. An attempt was made to preserve established location numbers to facilitate comparisons between this and prior publications. Readers wishing to cross reference this and prior reports should verify well identity via the construction details and descriptions provided in Appendix A.

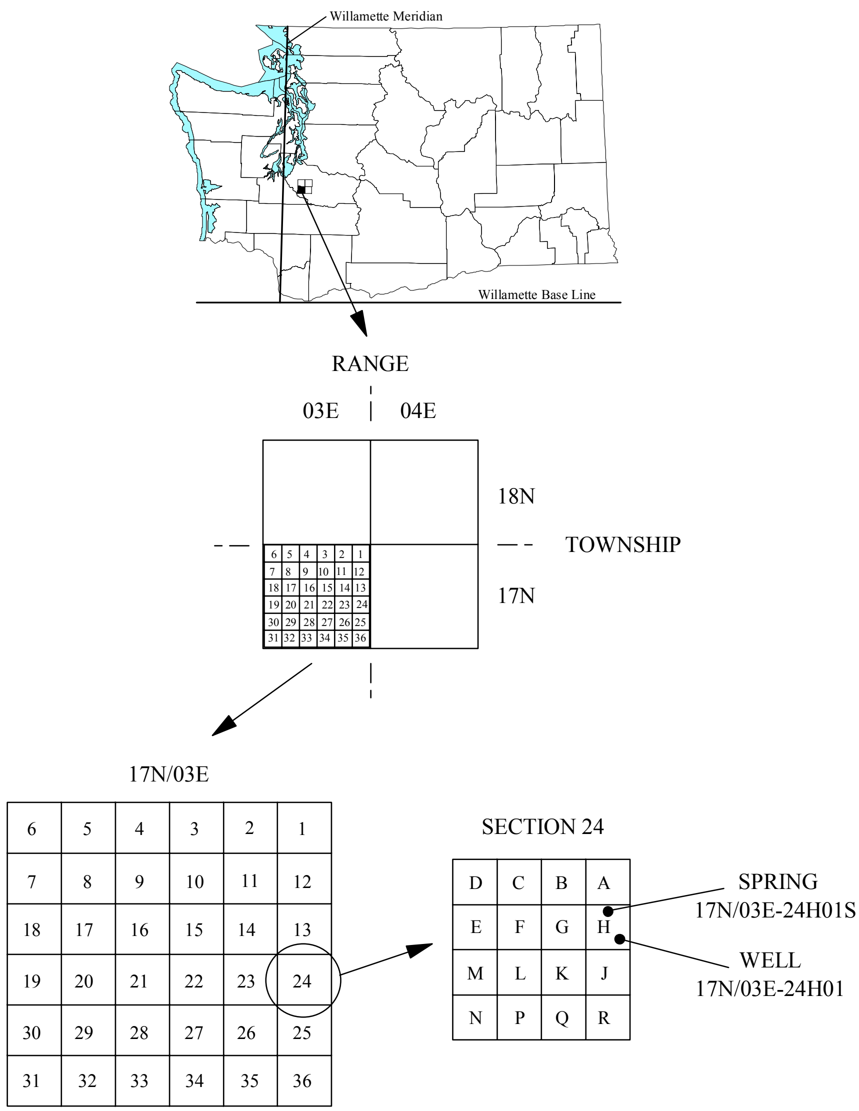

Figure 2 - Well and spring numbering and location system

All wells monitored during this study for water level or water quality were assigned unique well-identification numbers consisting of three letters followed by three numbers (i.e., AFC085). The identification number was stamped on an aluminum tag that was securely attached to the well casing or another permanent fixture of the water system.

Previous Investigations

This study drew upon detailed geologic mapping and hydrologic data collected by prior investigators working within the Muck Creek watershed and vicinity. Interpretations of the area surficial geology and water resource development potential were provided by Mundorff et al., 1955; Griffin et al., 1962; Walters and Kimmel, 1968; Brown and Caldwell, 1985; Walsh et al., 1987; Robinson and Noble, 1992; Jones, 1999; and Jones et al., 1999. Streamflow data and localized evaluations of surface-water and groundwater interchange are provided by Pearson and Dion, 1979, and Engle, 1997.

Study Methods

This study made extensive use of historic data contained within computerized databases maintained by Ecology and the USGS. This section provides descriptions of the methods used to compile historic data records, collect additional data, and perform data analysis.

Historic Data Compilation

Data compilation for this study began in August 1999 when well, spring, and historic streamflow records were downloaded from computerized databases maintained by Ecology and the USGS. A subsequent search of Ecology's paper files, published reports, and Internet sites provided additional information on area streamflow, climate, geology, and wells. A subset of 155 wells and 16 springs previously inventoried by Ecology or USGS personnel was selected from the compiled records for follow-up evaluation. Site selection was based on the availability of a drillers log (for wells), the reported accuracy of the well or spring location, the availability of historic groundwater level or spring-discharge measurements, and the desire to obtain a representative distribution of wells within the watershed.

A digital coverage of the selected wells and springs was prepared from the reported latitude/longitude coordinates for each site using Arcview® Geographic Information System (GIS) software. The sites were then plotted on 1/24,000-scale digital topographic maps and the site elevations compared to those reported during the initial field inventory. If the inventoried site altitude varied from the "plotted" altitude by more than 10 feet, the well or spring was flagged for a follow-up field visit to verify site location and elevation. During the follow-up visits, well and spring locations were determined using a satellite based Global Positioning System (GPS) receiver with a purported horizontal accuracy of approximately 10 meters. Elevations for the GPS sites were subsequently determined from 1/24,000-scale digital topographic maps based on their new plotted locations.

Field Methods

After the historic data compilation and site inventory were completed, 15 additional wells were inventoried and scheduled for monthly visits to track seasonal groundwater level changes and, where possible, groundwater temperature and specific conductance. Groundwater levels were measured with an electric tape or steel tape, using standard measurement techniques (Stallman, 1983). The electric tape measurements are accurate to 0.1 foot, while the steel tape readings are considered accurate to 0.01 foot.

To ensure representative water quality values, the sampled wells were purged at a rate of approximately five gallons per minute using the installed pump and water distribution system. Grab samples were collected at approximately three-minute intervals as purging progressed, and were measured using a YSI TLC combination field meter or a Multiline P4 universal meter and Tetracon 325 conductivity/temperature probe. All meters were calibrated or checked daily against known standards in accordance with the project quality assurance plan (Sinclair, 2000).

Water-quality values were considered stable when two successive grab samples yielded comparable results (i.e., there was less than a 10 percent difference from the mean of two grab samples for all parameters). The locations and physical descriptions of all inventoried wells and springs are shown on Figure 3 and Appendix A, respectively.

To help define the vertical hydraulic gradient and direction of flow between area streams and groundwater, Ecology installed 13 instream piezometers at readily accessible sites along Muck, South, and Lacamas creeks. Herrera Environmental Consultants Inc. (Herrera) later installed additional instream piezometers along Muck and South creeks within the Fort Lewis portion of the watershed. To obtain a better coverage of the central watershed, six of the piezometers installed by Herrera were also monitored during the latter several months of this study.

The instream piezometers (both Ecology's and Herrera's) consisted of a seven foot length of ½-inch diameter galvanized pipe (Figure 4). The lower end of each piezometer was crimped shut to form a drive point and was then perforated along the bottom six inches with several ⅛-inch diameter holes to allow water entry. The upper end of each piezometer was threaded and fitted with a standard pipe coupler to provide a robust "strike" surface and to protect the piezometer from damage during installation. The coupler also accepted a threaded plug, enabling the piezometers to be capped between monitoring events. The piezometers were installed approximately two to four feet from the stream edge using a fence post driver. The piezometers were driven to a maximum depth of approximately five feet or until downward progress was no longer possible. After installation, the piezometers were developed with a peristaltic pump to ensure they had a good hydraulic connection with the streambed sediments. The location and construction details of the monitored piezometers are shown on Figure 5 and Table 1, respectively.

Water levels in the piezometers were measured monthly during the study using either a manometer board or an electric tape. Both methods yield comparable results and are capable of reliably detecting head differences of 1cm or more. A manometer board (which enables simultaneous measurement of the piezometer and stream water levels) was used during the first few months of data collection, but was rendered ineffective when the stream and/or several of the piezometers went dry. Winter et al. (1988) provides a detailed discussion of manometer board construction and use.

During the remainder of the study, stream stage was measured by aligning an engineers tape parallel to the piezometer pipe and measuring the distance from the stream surface to the top of the piezometer. The inside (piezometer) water level was also measured from the top of the piezometer using an electric tape. For severely angled (off-vertical) piezometers these "raw" field measurements were corrected using simple trigonometric relationships to yield true depth to water measurements. The difference in water level between the piezometer and the stream indicates the direction of water flow. When the piezometer head exceeds (is higher than) the stream stage, groundwater discharge into the stream can be inferred. Similarly, when the stream stage exceeds the piezometer head, loss of water from the stream to groundwater can be inferred.

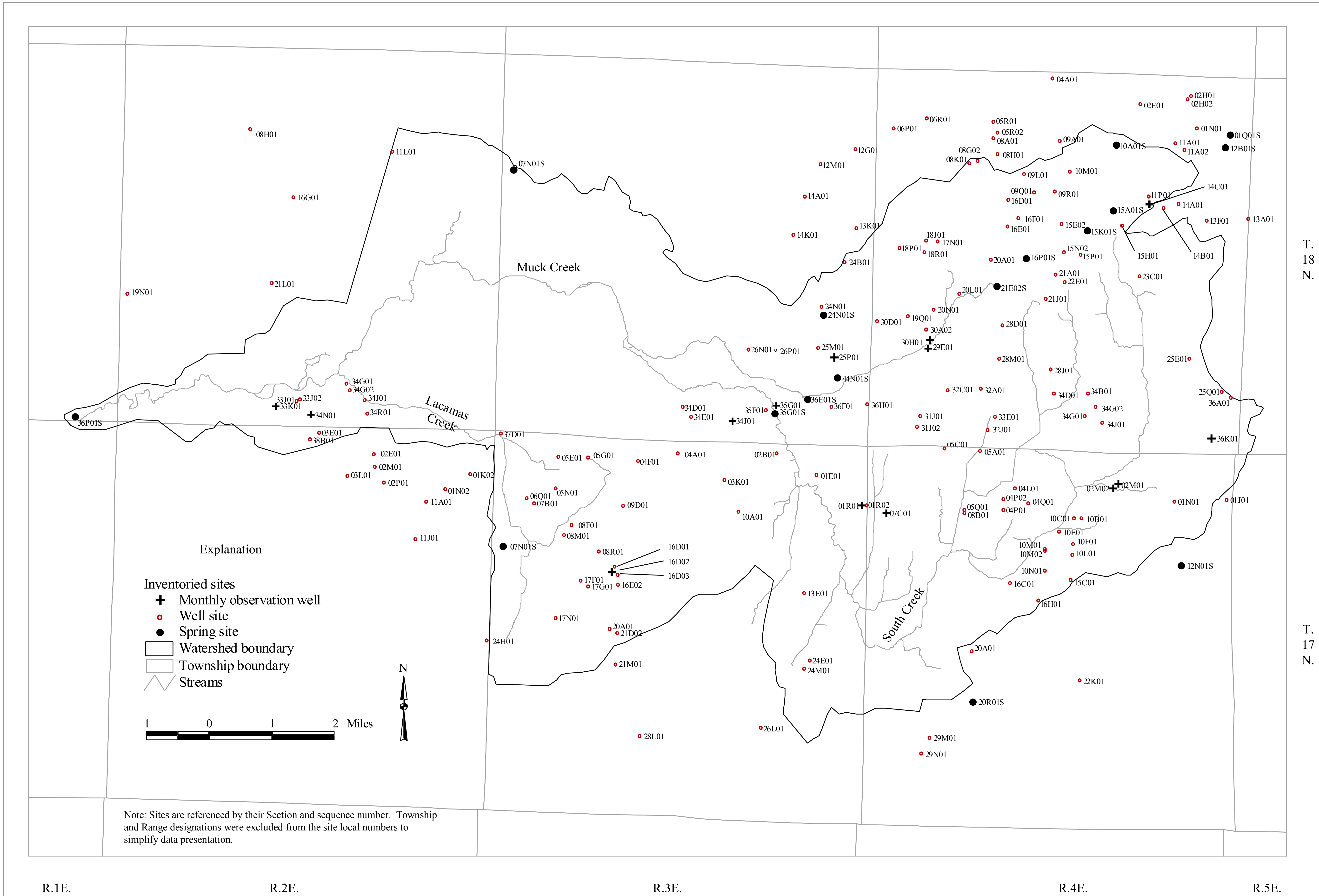

Figure 3

Location of inventoried wells and springs

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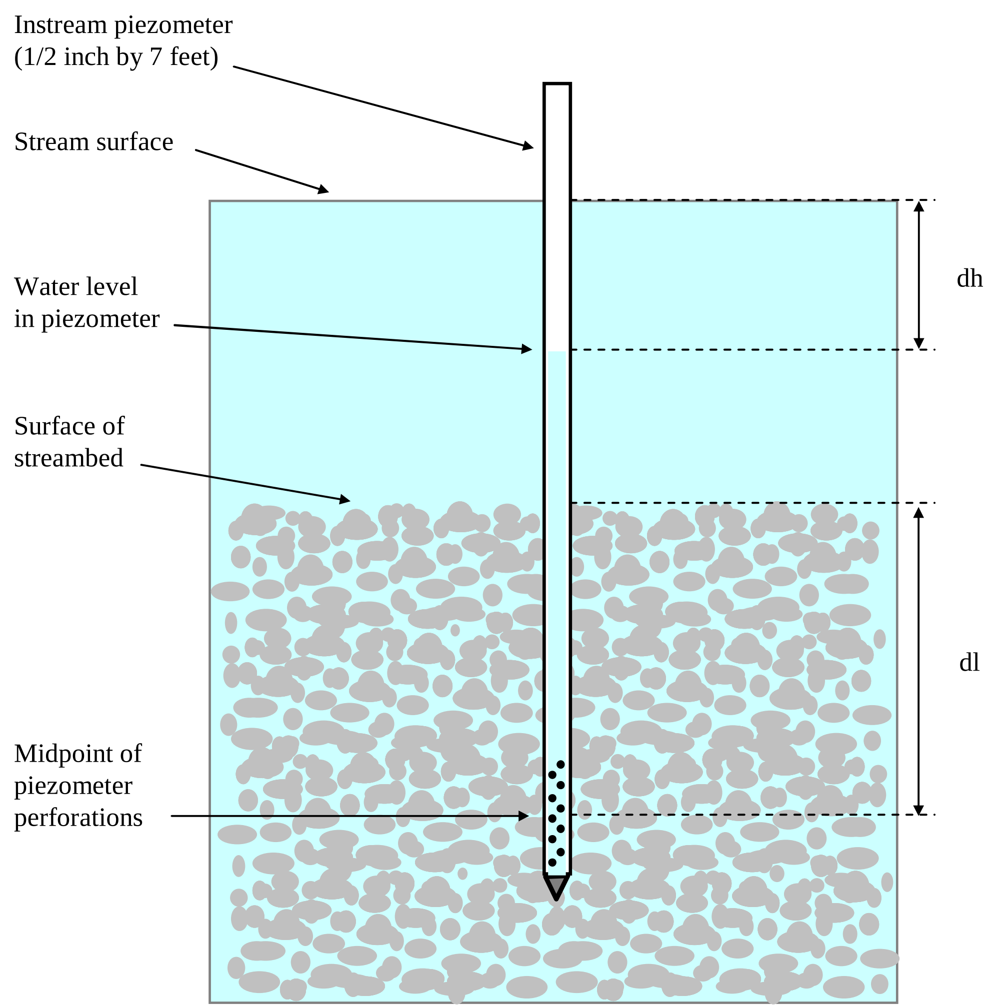

(diagram not to scale)

Figure 4 - Schematic of a typical instream piezometer installation

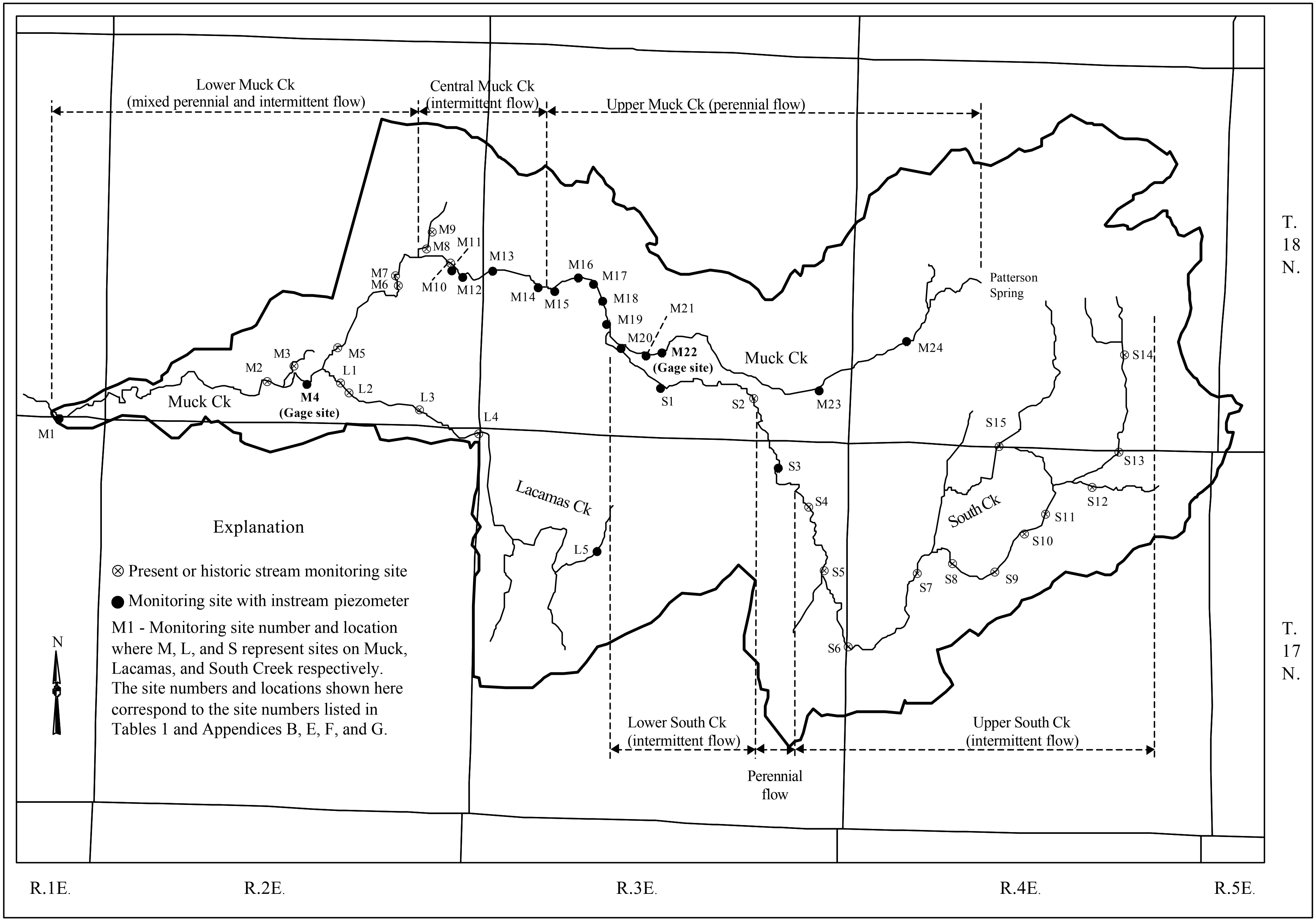

Figure 5 - Location of continuous streamflow gages, instream piezometers, and miscellaneous streamflow sites within the Muck Cr

Table 1 - Physical Description and Location of Instream Piezometers

Map ID[1]	Piezometer location	Site Latitude (dms.s)	Site Longitude (dms.s)	River Mile[2] (miles)	Site Altitude[3] (feet)	Piezometer Stickup Above Streambed (feet)	Piezometer Depth Below Streambed (feet)	Depth to Midpoint of Perforations (feet below streambed)
M1	Muck Ck at Mouth	465950.0	1223739.0	0.03	100	4.3	2.7	2.45
M4	Muck Ck at Warren Street, in Roy	470020.2	1223230.8	5.5	310	4.1	2.9	2.65
M11	Muck Ck at State Hwy 507, near Roy	470158.4	1222934.8	9.4	360	4.5	2.5	2.25
M12	Muck Ck at piezometer HEC-12	470151.6	1222921.1	9.7	365	5.1	1.9	1.65
M13	Muck Ck at piezometer ECY-3	470155.6	1222845.8	10.2	375	3.8	3.2	2.95
M14	Muck Ck at piezometer ECY-4	470144.4	1222749.3	11.0	382	4	3.0	2.75
M15	Muck Ck at piezometer HEC-9	470142.6	1222729.2	11.3	383	2.9	4.1	3.85
M16	Muck Ck at piezometer HEC-7	470152.0	1222659.6	11.8	385	3.3	3.7	3.45
M17	Muck Ck at piezometer ECY-5	470148.0	1222641.0	12.0	387	4	3.0	2.75
M18	Muck Ck at 8th Ave S	470135.0	1222631.6	12.3	388	4.9	2.1	1.85
M19	Muck Ck at piezometer HEC-6	470116.0	1222622.0	12.7	390	3.7	3.3	3.05
M20	Muck Ck at piezometer HEC-2	470056.5	1222605.3	13.2	392	3.7	3.3	3.05
M21	Muck Ck at piezometer HEC-1	470051.1	1222535.0	13.7	395	3.7	3.3	3.05
M22	Muck Ck at 8th Ave E	470054.0	1222513.0	14.0	398	2.8	4.2	3.95
M23	Muck Ck at Weiler Rd	470026.6	1222201.6	17.0	440	2.6	4.4	4.15
M24	Muck Ck at 70th Ave E	470107.3	1222015.4	18.7	470	2.3	4.7	4.45
L5	Lacamas Ck at 8th Ave S	465811.0	1222629.0	7.5	445	2.4	4.6	4.35
S1	South Creek at 8th Ave E	470025.2	1222515.2	1.3	405	3.7	3.3	3.05
S3	South Creek near 294th St E	465922.6	1222249.1	4.3	455	3.6	3.4	3.15

[1] The listed Map ID corresponds to the site number shown on Figure 4

[2] River mile location refers to the site distance, in river miles, from the respective stream mouth

[3] Site altitudes were determined from 1:24000 scale topographic maps and are accurate to +- 5 or 10 feet, depending on the map contour interval

The vertical hydraulic gradient between the stream and instream piezometers was calculated as follows:

i_v= dh/dl

where: i_v is the vertical hydraulic gradient (L/L),
dh is the difference between the stream stage and the piezometer water level (L),
dl is the distance from the stream bed to the midpoint of the piezometer perforations (L)

Negative values of i_v indicate loss of water from the stream to groundwater, while positive values indicate groundwater discharge into the stream (Appendix B). Actual gradients were calculated when both the stream and piezometer contained water. When only the stream contained water (i.e., the piezometer was dry), minimum potential gradients were calculated by assuming that the piezometer water level was equal to the bottom of the piezometer intake. Gradients could not be calculated when the stream was dry and the piezometer contained water that lay at an elevation below the stream bed.

The piezometers and stream were also sampled for temperature and specific conductance during each monitoring event to provide an additional means of verifying the gradient relationships described above. Piezometers exhibiting negative hydraulic gradients generally have temperature and specific conductance signatures that are quite similar to surface water, since the stream is recharging groundwater at that location. Piezometers with positive hydraulic gradients typically have more stable temperatures (less annual variability) that diverge from the stream temperature seasonally. Water from such piezometers is generally warmer than the stream during the cool winter months and cooler than the stream during the warm summer months.

Water quality at the stream center was measured in situ, using the above described field meters. The procedure for sampling the piezometers is similar to that previously described for the water level observation wells. The primary difference is that the piezometers were purged with a peristaltic pump at a rate of approximately 500 ml per minute. As with the monthly observation wells, water quality values were considered stable when two successive grab samples yielded comparable results. The piezometer water level and water quality measurements are shown in Appendix B.

Stream-seepage evaluations were conducted in June and September of 2000 to complement and verify the instream piezometer results. During the seepage evaluations, same-day discharge measurements were made at numerous sites along Muck, Lacamas, and South creeks. The relative increase or decrease in discharge between measurement sites that could not be accounted for through tributary input or out-of-stream diversions is a net measure of the water exchanged between the stream and groundwater.

The discharge measurements for this study were made using a Swoffer Model 2100 horizontal axis current meter or a Price AA current meter and the cross section method described by Rantz et al. (1982). Under field conditions, these meters are capable of reliably measuring streamflow to within 2 or 3 percent of the actual stream discharge (Rantz et al., 1982). If one assumes that the error associated with individual discharge measurements is additive, then seepage values that exceed 4 to 6 percent of total streamflow should represent a true gain or loss of water from the stream. Seepage values that comprise less than 4 to 6 percent of total streamflow may indicate actual water exchange or measurement error, and should be viewed with caution. All seepage volumes measured during this study exceeded the 4 to 6 percent measurement threshold and are thus considered reliable indicators of streamflow gain or loss. The seepage results and associated streamflow measurements are shown in Figure 6.

Data Analysis Methods

An aquifer's ability to transmit water is dependent on several factors such as the size, shape, arrangement, and degree of compaction or cementation of the materials which comprise the aquifer matrix. One means of quantifying an aquifer's water transmission capabilities is to define the hydraulic conductivity of the aquifer matrix. Hydraulic conductivity is a coefficient that describes the rate of water movement through a porous medium. For this study, hydraulic conductivity was estimated from specific capacity information reported on well construction logs. Specific capacity is a rough measure of a well's production potential and is equal to the well's pumping rate divided by the resultant drawdown.

One hundred and ten inventoried wells were evaluated during this analysis, of which 88 contained complete specific capacity information (pumping rate, test duration, drawdown, and well construction log). The test duration was not specified for the remaining 22 wells but was assumed to be one hour for the purpose of this analysis. If the actual pumping period for a well was longer than one hour, this assumption will yield lower estimates of hydraulic conductivity than would have been obtained had the actual pumping time been used.

Horizontal hydraulic conductivity values for open-ended wells (those without screens or casing perforations) were calculated using Bear's (1979) equation for hemispherical flow to an open-end well that just penetrates (barely enters) an aquifer. When modified to describe spherical flow to an open-ended well that is completed within an aquifer, the equation becomes:

$$K_h = \frac{Q}{4\pi sr}$$

where:

- K_h is the horizontal hydraulic conductivity of the unit in feet per day
- Q is the well discharge or pumping rate in cubic feet per day
- s is drawdown in the well, in feet
- r is the well radius, in feet

This equation assumes that the horizontal and vertical hydraulic conductivity of the pumped unit are equal, and that water flows uniformly in all directions. These assumptions are probably incorrect, given the heterogeneous nature of the study area deposits. Accordingly, the formula likely underestimates K_h by an unknown factor.

For screened or perforated wells, horizontal hydraulic conductivity values were calculated using a computer program developed by Bradbury and Rothschild (1985). The program iteratively solves a modified version of Theis's equation to estimate transmissivity from the specific capacity of wells (Theis et al., 1963). As shown here, Theis's equation has been modified to incorporate corrections for well loss and partial penetration effects using equations proposed by Csallany and Walton (1963) and Brons and Marting (1961), respectively.

$$T = \frac{Q}{4\pi (s - s_w)} \left[\ln\left(\frac{2.25\ Tt}{r_w^2 S}\right) + 2\ s_p \right]$$

where: T = transmissivity (L^2/t)

Q = the well discharge or pumping rate (L^3/t)

s = drawdown in the well (L)

t = the duration of pumping (t)

S = the formation storage coefficient (dimensionless)

values assumed for analysis: 0.0002 for confined conditions

0.2 for unconfined conditions

r_w = the radius of the well (L)

Tt = the initial estimate of transmissivity used by the program (L^2/t)

s_w = the well loss correction factor (L)

s_p = a factor to correct for partial penetration

The transmissivity values estimated by the program were divided by the length of the screened or perforated interval for each well to obtain horizontal hydraulic conductivity values in units of feet per day (ft/day) (Appendix A). The assumption that the open interval for a well is equal to the total aquifer thickness may yield high estimates of horizontal hydraulic conductivity. However, the amount of error introduced by this assumption is probably small, due to natural layering within and between aquifers which favors horizontal flow.

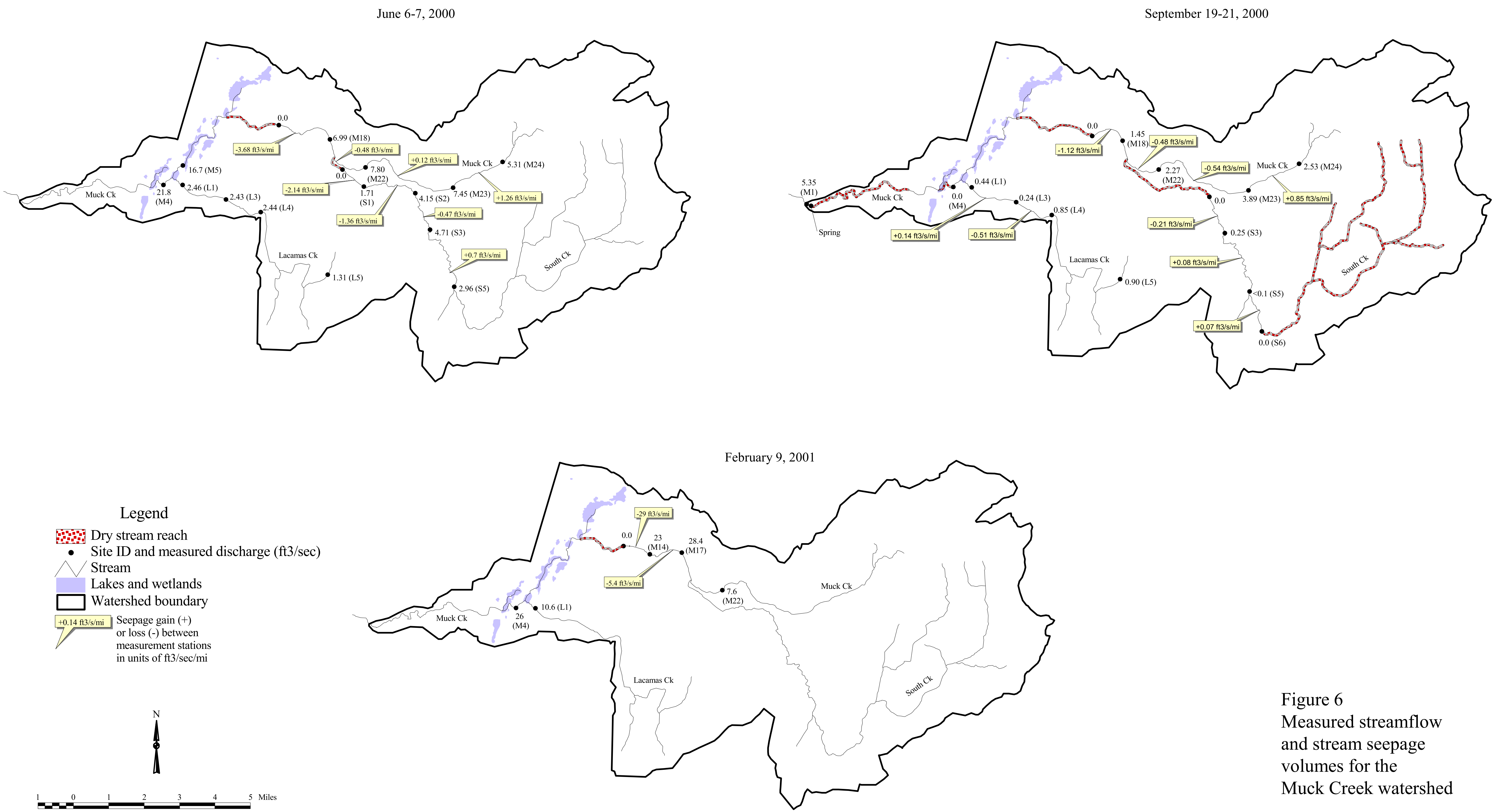

Figure 6
Measured streamflow
and stream seepage
volumes for the
Muck Creek watershed

blank back for figure 6

Geologic Setting

The Muck Creek watershed, like most of the Puget Sound lowland, is underlain by a thick sequence of unconsolidated sediments ranging from Holocene to Miocene in age. These sediments were deposited upon Eocene-age bedrock by glacial and non-glacial processes, and vary from less than 100 feet in thickness near the southern and eastern watershed perimeter to more than 1500 feet near the northern perimeter (Jones, 1996) (Figure 7).

Within the broader sedimentary record of the Puget Sound lowland, there is evidence to support the delineation of at least four major (continental) glacial episodes and numerous minor glaciations (Jones, 1999). Most of the near-surface geologic deposits within the study area were deposited approximately 13,000 to 15,000 years ago, during the last major glacial advance into the Puget Sound lowland. This glaciation, called the Vashon Stade of the Frasier glaciation, began approximately 15,000 years ago as the global climate cooled and a continental ice mass formed and advanced south from British Columbia.

As the Vashon glacier advanced, it split to form two lobes. The Juan de Fuca lobe moved west and blocked the Strait of Juan de Fuca, while the Puget lobe flowed south into the Puget Sound lowland. At its maximum extent, the Puget lobe extended to just beyond Tenino in southern Thurston County, and spanned from the Cascade Range to the Olympic Mountains.

With the advance of the Puget lobe, once northward-flowing rivers and streams were blocked and diverted southward, where they formed large lakes beside and in front of the advancing glacier. Sediment-laden meltwater from the glacier and surrounding mountains deposited thin layers of sand, silt, and clay in the progressively deepening lakes. The lakes eventually filled to the point that drainage pathways were opened through the Chehalis River valley to the west and southwest, and flow to the Pacific Ocean was reestablished.

As the global climate began to warm approximately 13,500 years ago, the Puget lobe retreated northward. During retreat several drainage pathways, including the Muck Creek channel, were cut by westward flowing high-energy-meltwater streams that ran along the terminal face of the glacier. These streams were fed by melting ice, diverted streamflow, and periodic outbursts from ice-dammed-glacial lakes, and subsequently deposited coarse grained recessional outwash within and to the west of the excavated channel. Eventually the glacier retreated far enough that northern drainage pathways were reestablished via the Strait of Juan de Fuca, and marine water once again occupied the Puget lowlands.

During its advance and subsequent retreat, the Vashon glacier reworked and overrode the deposits of prior glaciations. As it did so, it left a characteristic sequence of glacial deposits that can be grouped into two dominant categories: outwash and till. Outwash typically consists of moderately-to-well sorted gravel and sand that was deposited by meltwater streams during glacial advance and retreat. Till, in contrast, was deposited directly by the ice and consists of unsorted deposits of sand, gravel, and boulders in a silt and clay matrix.

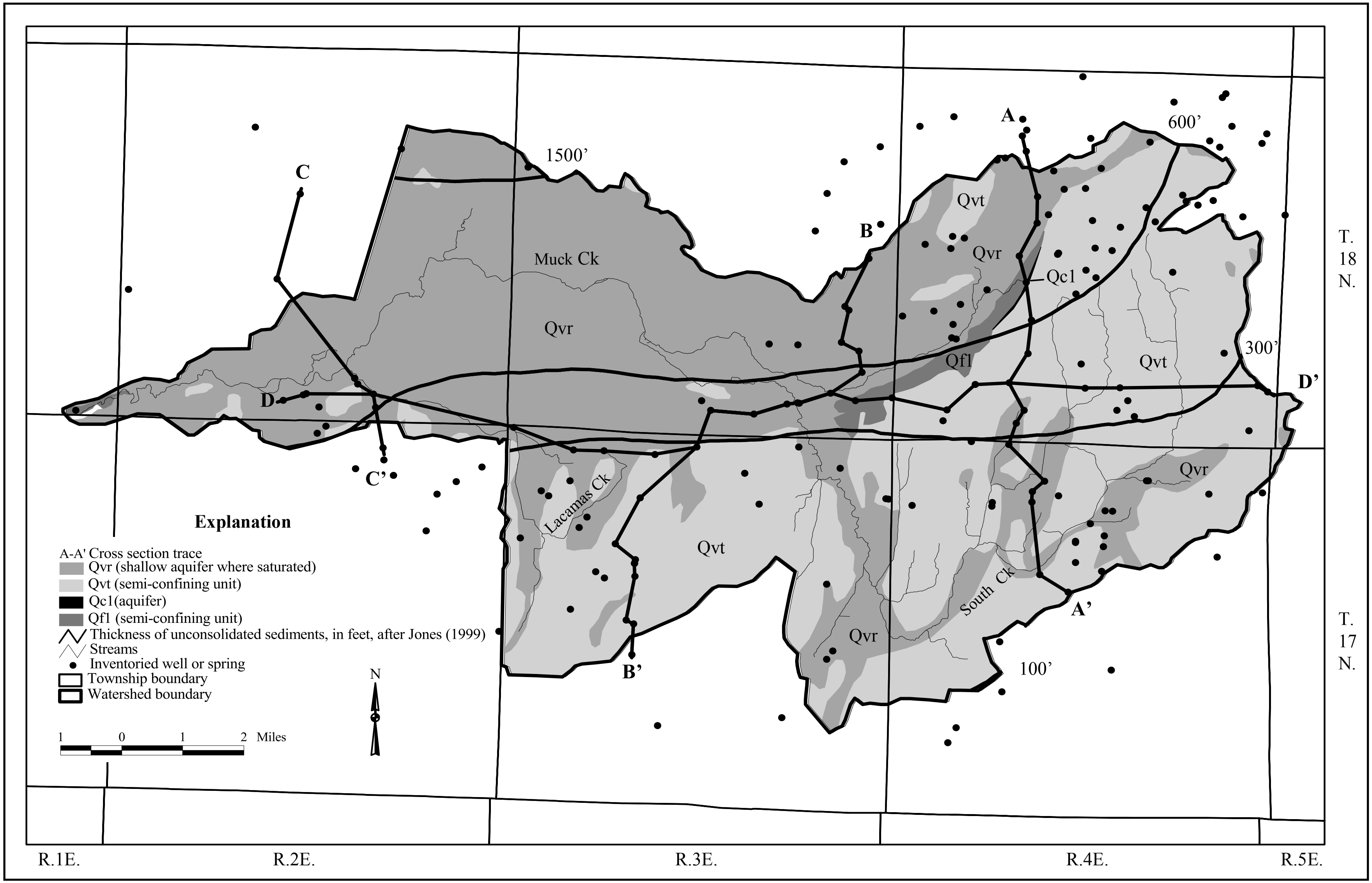

Figure 7 - Distribution of hydrogeologic units at land surface, inventoried wells and springs, and cross section traces, Muck Creek watershed

The youngest geologic units in the study area are Holocene-age alluvium and recent deposits of organic-rich peat and muck. The alluvial deposits consist of gravel, sand, and silt, laid down by modern streams within or adjacent to Muck and South creeks. The peat and muck deposits are also of limited extent, and are largely restricted to closed depressions or to narrow zones adjacent to the present channels of Muck, South, and Lacamas creeks.

The next youngest geologic unit, Vashon recessional outwash, was deposited by meltwater streams as the Puget lobe retreated. This unit blankets land surface throughout most of the Muck Creek drainage, where it consists mostly of the Steilacoom gravel facies of Willis (1898) and lesser deposits of coarse to fine grained outwash. Steilacoom gravel is unusual in that it is consistently coarse and occupies a several square mile area south and southwest of Tacoma (Walters and Kimmel, 1968). It consists largely of one- to three-inch pebbles with occasional boulders up to 1.5 feet in diameter. It is thought to have been deposited and/or reworked by meltwater discharge from proglacial Lake Puyallup which occupied the Puyallup Valley during glacial retreat.

Within the South Creek and Lacamas Creek drainage's, Vashon recessional outwash is generally restricted to linear south-southwest trending outwash channels (Figure 7). These deposits consist of poorly to moderately well sorted sand, gravel, and boulders that were deposited in, along, or in front of the glacier by meltwater streams as the Vashon Glacier retreated.

Vashon till underlies Vashon recessional outwash throughout most of the Muck Creek drainage, and blankets ground surface within the South Creek drainage where the recessional outwash is generally absent. Where the till was deposited and overridden by ice, it consists of a compact unsorted mixture of sand, gravel, and boulders in a clay and silt matrix. Where it was deposited during glacial retreat, the till is less compact.

Vashon advance outwash is the oldest of the Vashon age deposits. It was deposited by meltwater streams in front of the advancing glacier, and underlies Vashon till in most areas of the watershed. It outcrops at land surface in a narrow band along the southern border of the Muck Creek channel where it provides water to springs and seeps. This unit generally consists of poorly to moderately well sorted sandy gravel or sand, but may contain lenses of silt or clay. Because it was subsequently overridden by ice, the advance outwash tends to be more compact than the recessional deposits that were laid down as the ice retreated.

A considerable thickness of alternating coarse and fine-grained sediments underlies Vashon-age deposits throughout most of the study area. These pre-Vashon deposits are both glacial and non-glacial in origin, and extend to a depth of at least 1500 feet below ground surface near the northwest corner of the watershed (Figure 7). Readers are referred to the work of Walters and Kimmel (1968) for a detailed discussion of these deposits.

Hydrogeologic Units

The occurrence and movement of groundwater within the earth's subsurface is controlled in large part by the distribution of high and low permeability geologic materials. Permeable material, such as glacial outwash, more readily stores and transmits water than lower permeability material, such as till. A convenient means of acknowledging this difference is to subdivide or group geologic units into hydrogeologic units on the basis of their water production potential. Hydrogeologic units that store and readily transmit groundwater are called aquifers, while those that transmit relatively little water are called aquitards or confining units.

For this study the watershed's geologic units were grouped and/or subdivided into five aquifers units (Qvr, Qc1, Qc2, Qc3, and Qc4) and four confining units (Qvt, Qf1, Qf2, and Qf3). The designation Qdu was used to identify areas where there is insufficient information to designate a unique hydrogeologic unit (Figure 8, Table 2, and Appendix C). Unit designations were interpreted using surficial geology maps, estimates of horizontal hydraulic conductivity, driller reported lithologic descriptions, and water levels from inventoried wells (Appendices A and D).

Table 2. Study Area Hydrogeologic Units and Typical Thickness

Hydrogeologic Unit	Typical Unit Thickness (feet)	Average Thickness (feet)
Unit Qvr	0-45	18
Confining Unit Qvt	0-141	60
Aquifer Qc1	4-40	15
Confining unit Qf1	4-86	47
Aquifer Qc2	27-70	35
Confining unit Qf2	3-51	18
Aquifer Qc3	2-72	26
Confining unit Qf3	7-73	30
Aquifer Qc4	unknown	---
Qdu	unknown	---

It is important to acknowledge that the process of defining hydrogeologic units on the basis of driller boring logs is highly subjective. The task is complicated by differences in the way individual well drillers described the material they encountered during well construction. In addition, such descriptive differences must be reconciled with the natural heterogeneity of the materials themselves, which can vary widely in texture and composition over short distances. The aquifer units defined here consist mostly of sand and gravel but may contain localized lenses or accumulations of silt or clay. Similarly, the confining units consist mostly of silt or clay but may contain localized lenses of sand and gravel. As defined here, individual aquifers or confining units may contain sediments from one or more geologic unit and may contain both glacial and non-glacial material.

Unit Qvr occurs at land surface throughout most of the Muck Creek drainage and in narrow zones along the major stream channels within the Lacamas and South creek drainages (Figures 7 and 8). Within the Muck Creek drainage this unit is composed principally of coarse gravel, cobbles, and boulders associated with the Steilacoom Gravel facies of Willis (1898). Within the Lacamas and South Creek drainage's, unit Qvr consists of Vashon recessional sand and gravel but may contain localized lenses of silt or clay. In some areas recent alluvium, bog, and peat deposits were also included in this unit. Based on wells inventoried during this study, unit Qvr averages 18 feet in thickness and varies from a thin veneer to 45 feet thick. In the western watershed, where Qvr is thick enough to intersect the water table, it can be a highly productive aquifer.

Confining unit Qvt underlies Qvr throughout most of the Muck Creek drainage and blankets land surface throughout much of the Lacamas and South Creek drainage's (Figures 7 and 8). It also occurs at land surface within the Muck Creek drainage where Qvr is absent. Qvt is comprised largely of Vashon-age till (often called "hardpan" in drillers' logs) and consists of compact, poorly sorted deposits of clay, and silt-bound sand and gravel. In some areas, recent-localized bog and peat deposits were also included in this unit. Where Qvt contains saturated sand or gravel lenses, it can yield sufficient water to supply the domestic needs of a household (Walters and Kimmel, 1968). In most areas, however, it contains little usable water and serves as a regional confining or semi-confining unit. Based on wells evaluated during this study, Qvt averages 60 feet in thickness and varies from a thin veneer to 141 feet thick.

Aquifer Qc1 underlies unit Qvt throughout much of the upper South Creek drainage where it is tapped by numerous domestic and public supply wells (Figures 7 and 8). It consists largely of sand and gravel but also contains extensive lenses of silt or clay. Aquifer Qc1 is generally confined except where it outcrops along the southern margin of the Muck Creek channel and provides water to numerous springs and seeps. Based on wells evaluated during this study, aquifer Qc1 averages 15 feet in thickness and ranges from 4 to 40 feet thick.

Confining unit Qf1 underlies aquifer Qc1 and consists mostly of silt and clay but may contain lenses of silty sand or gravel (Figures 7 and 8). Based on wells inventoried during this study, the unit averages 47 feet in thickness and varies from a few feet to 86 feet thick (Figure 8).

Aquifer Qc2 underlies confining unit Qf1 within the South Creek uplands and is composed mostly of sand and gravel but also contains occasional lenses of silt or clay (Figure 8). Qc2 is an important aquifer and is generally confined except where it outcrops and abuts unit Qvr along the southern margin of the Muck Creek channel. Based on wells evaluated during this study, unit Qc2 ranged from 27 to 70 feet thick and averaged 35 feet.

Confining unit Qf2 underlies aquifer Qc2 within the South Creek uplands and abuts unit Qvt along the southern margin of the Muck Creek channel (Figure 8). It consists mostly of silt and clay but also contains lenses of sand or gravel. Based on wells inventoried during this study, unit Qf2 averages 18 feet in thickness and ranges from a few feet to approximately 50 feet in thick.

Aquifer Qc3 underlies confining unit Qf2 within the South Creek upland and unit Qvt within the Muck Creek drainage (Figure 8). Qc3 is a significant aquifer and source of water to single domestic wells within the Muck Creek drainage and is tapped by deeper public supply wells in the South Creek drainage. Qc3 consists largely of sand and gravel but also contains lenses of silt and clay. Based on wells evaluated during this study, aquifer Qc3 ranged from a few feet to approximately 70 feet in thickness and averaged 26 feet.

Confining unit Qf3 underlies aquifer Qc3 throughout the study area and consists mostly of silt and clay with occasional lenses of sand or gravel (Figure 8). Based on the wells evaluated during this study, Qf3 ranged from 7 to 73 feet in thickness and averaged approximately 30 feet.

Aquifer Qc4 underlies unit Qf3 within the Muck Creek drainage and consists of sand and gravel deposits with minor lenses of silt or clay (Figure 8). No wells completely penetrate this unit, so its total thickness is unknown.

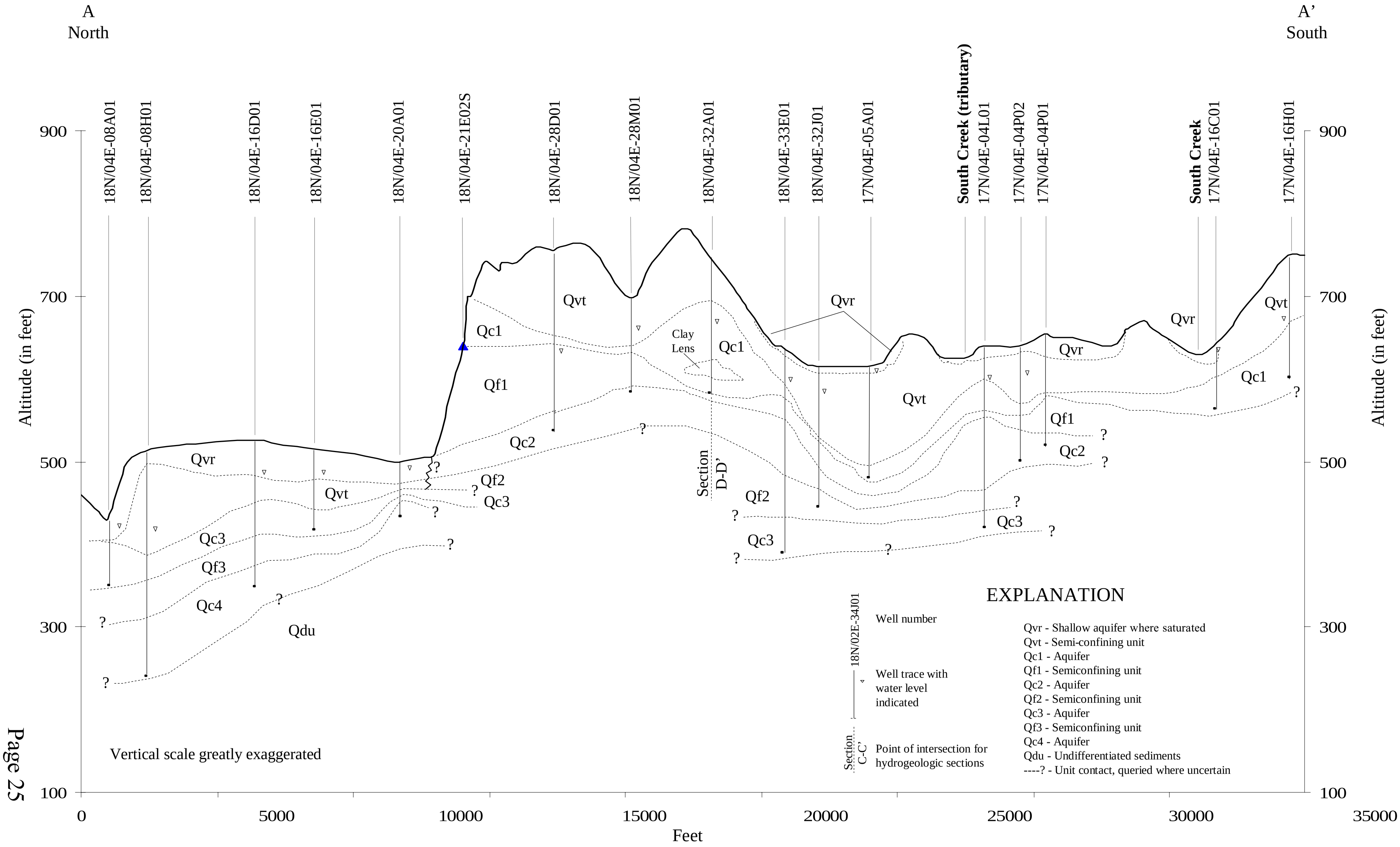

Figure 8 - Hydrogeologic cross sections A-A' to D-D' for the Muck Creek watershed

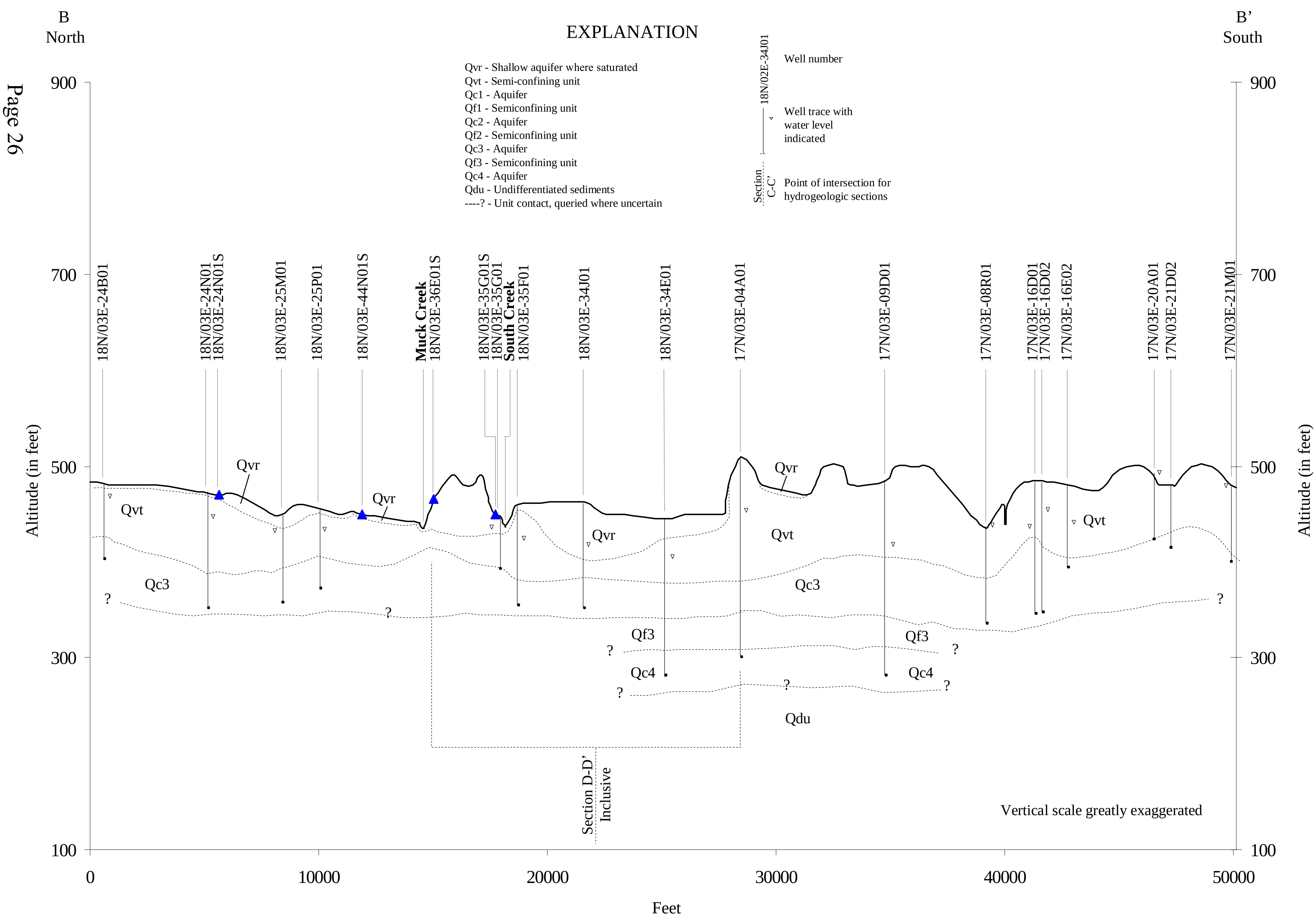

Figure 8 - (Continued) Cross-Section B-B'

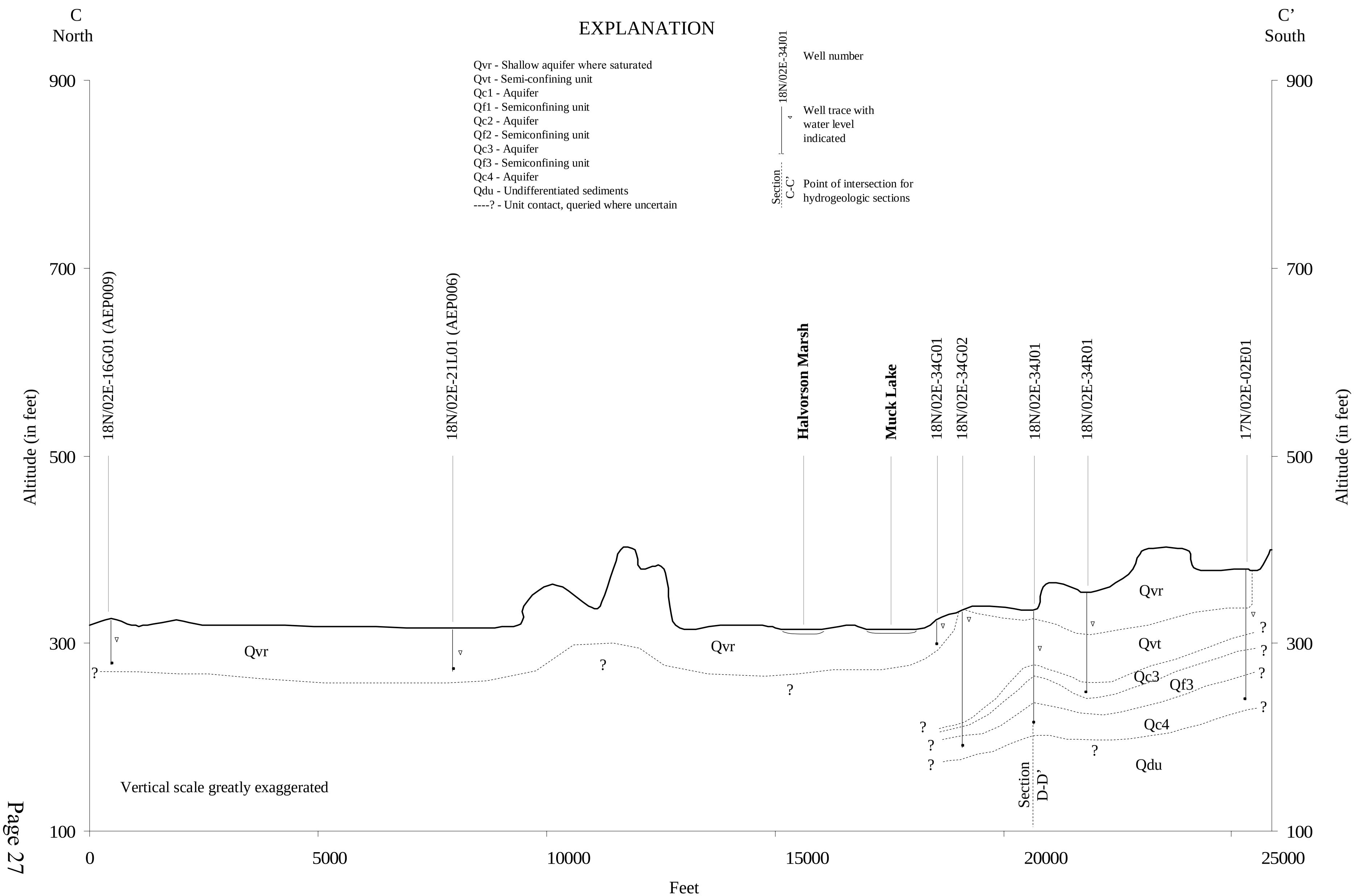

Figure 8 - (Continued) Cross-Section C-C'

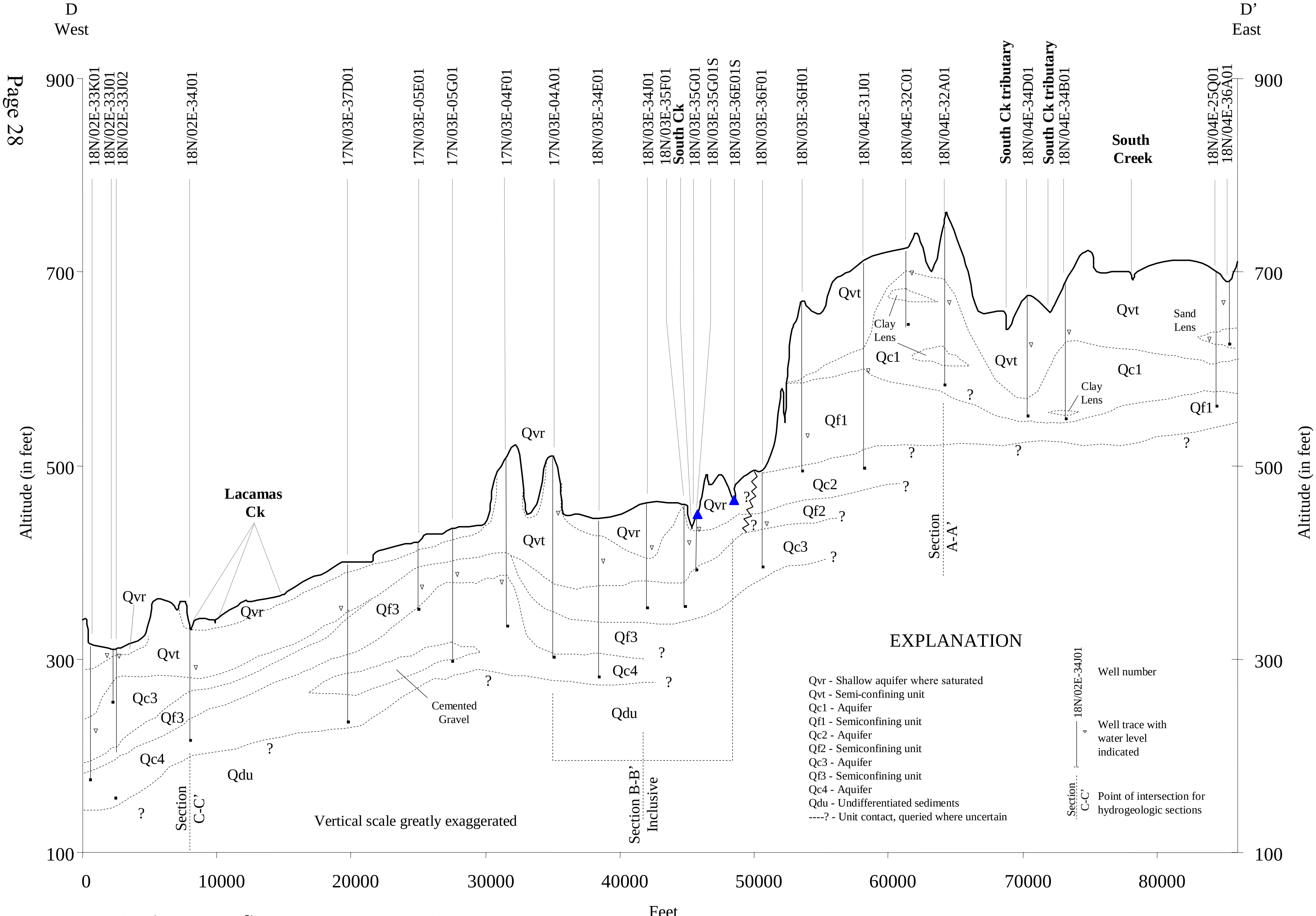

Figure 8 - (Continued) Cross-Section D-D’

Study Area Hydrologic System

The hydrologic cycle (Figure 9) provides a generalized but useful framework for describing and understanding the flow of water within a watershed. Within the global hydrologic cycle, water evaporates from the land and oceans and returns elsewhere to the earth's surface as rain or snow. For areas of little snowfall such as the Puget Sound lowland, a portion of the precipitation that falls on land quickly flows to streams or other surface waterbodies. Another portion infiltrates into the ground and is returned to the atmosphere through evapotranspiration, and some infiltrates beyond the root zone of plants to recharge groundwater.

Water within the hydrologic cycle is always in motion. Streams flow down hill to merge with rivers which ultimately flow to the ocean. Groundwater moves vertically within and between aquifers, and moves horizontally from recharge areas to points of natural discharge such as springs, streambed seeps, lakes, or the ocean.

The water cycle for an individual watershed may contain all or part of the elements of the global water cycle depending on the watershed location. The following discussion examines various aspects of the water cycle for the Muck Creek watershed including its climate, streamflow patterns, groundwater recharge and movement, and the role that surface-water and groundwater interchange plays in the watershed's hydrology.

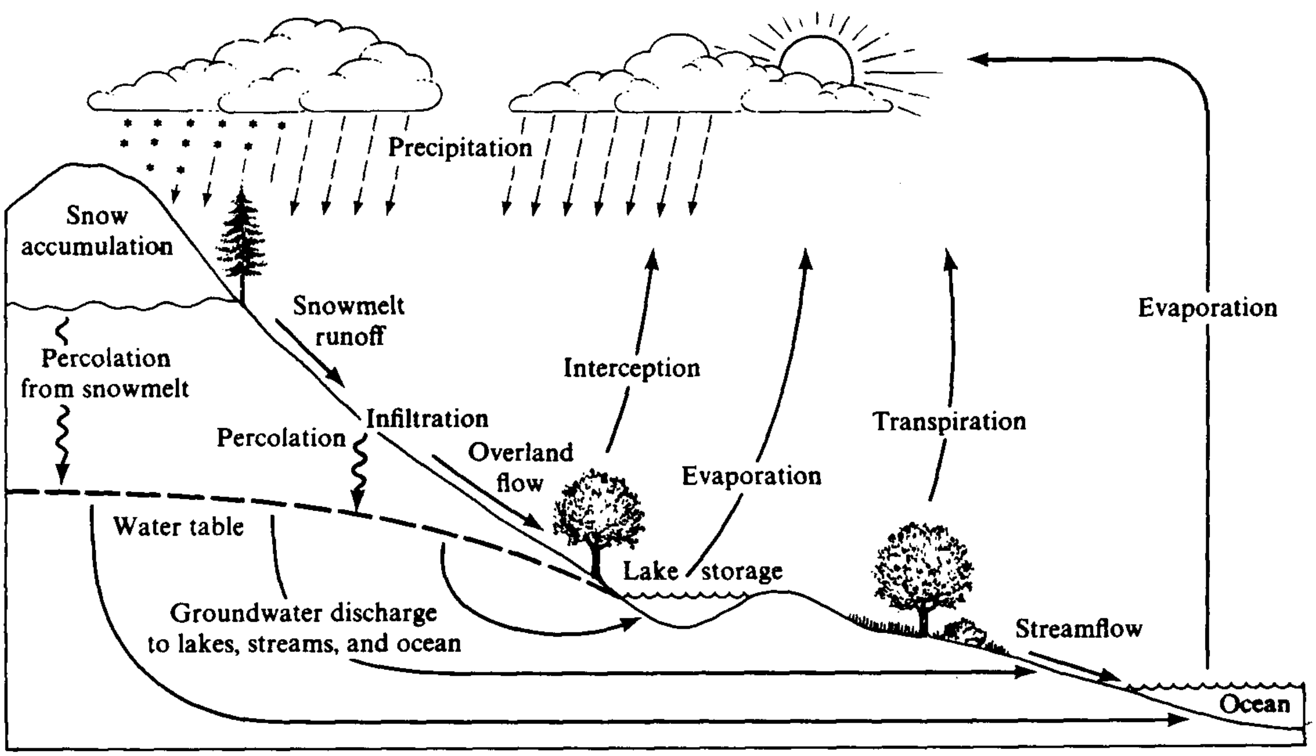

Figure 9 - Schematic diagram of the hydrologic cycle (after Dunne and Leopold, 1978)

Climate

The study area climate is typical of the Puget Sound lowlands and is characterized by mild, wet winters and warm, dry summers. Winter temperatures are generally above freezing, due to the low elevation of the watershed and the moderating effects of the Pacific Ocean. Summer temperatures rarely exceed 80° F for more than a few days at a time. Annual precipitation within the study area generally increases from northwest to southeast, and ranges from approximately 37 inches near Fort Lewis to approximately 43 inches near the southeastern watershed perimeter.

Precipitation patterns and trends for the study area were evaluated using data for the city of Tacoma, the closest long-term weather station. Precipitation records for Tacoma were obtained from the National Climate Data Center (NCDC) web site (stations 488278 and 458286). Three years (1960-61 and 1982) had several months of missing data and could not be used directly. Annual precipitation values for these years were synthesized from records for Puyallup (station 456803) using regression techniques[1].

Figure 10 depicts the total annual precipitation at Tacoma for 1919 through 1999, while Figure 11 shows the distribution of precipitation by month. It is evident from these figures that area precipitation is highly variable both annually and seasonally. The annual precipitation at Tacoma during this period averaged 36.68 inches, and ranged from 16.96 to 53.27 inches (Figure 10). Precipitation is generally greatest during November, December, and January, while July is typically the driest month (Figure 11). Roughly 85 percent of the annual precipitation at Tacoma falls as rain between September and April (Walters and Kimmel, 1968).

During this study, precipitation was significantly less than normal throughout much of Washington. Preliminary data suggest that only 23.46 inches, or roughly 64 percent of the station average precipitation, fell at Tacoma during calendar year 2000 (NCDC, 2001). This lack of precipitation persisted through most of 2001 as well, and resulted in the worst drought to affect Washington State since 1976-77 (Ecology, 2001).

Streamflow

Muck Creek was continuously gaged by USGS personnel at two locations in the past. The first gage was operated for a few months in 1949 (July to October) near Loveland (Figure 5, site M22) (State of Washington, 1955). A second gage at Roy (USGS 12090200) was operated from June 1956 to September 1971 (Figure 5, site M4). Gages were recently reestablished at both of these sites as part of a basin characterization study initiated by Pierce County and have been in continuous operation since late March 2000 (CH2mHill, 2000). In addition to the above gaging records, area streams have a rich history of miscellaneous discharge measurements (Pearson and Dion, 1979; Williams and Riis, 1989; Eylar et al., 1990). Site locations and data records for the continuous and miscellaneous discharge sites are shown on Figure 5 and Appendices E, F, and G.

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[1] Missing annual precipitation values for Tacoma (Tp) were synthesized from precipitation data collected at Puyallup (Pp) using the following equation: $Tp = 0.8135*(Pp) + 4.5431$ where $R^2=0.83$

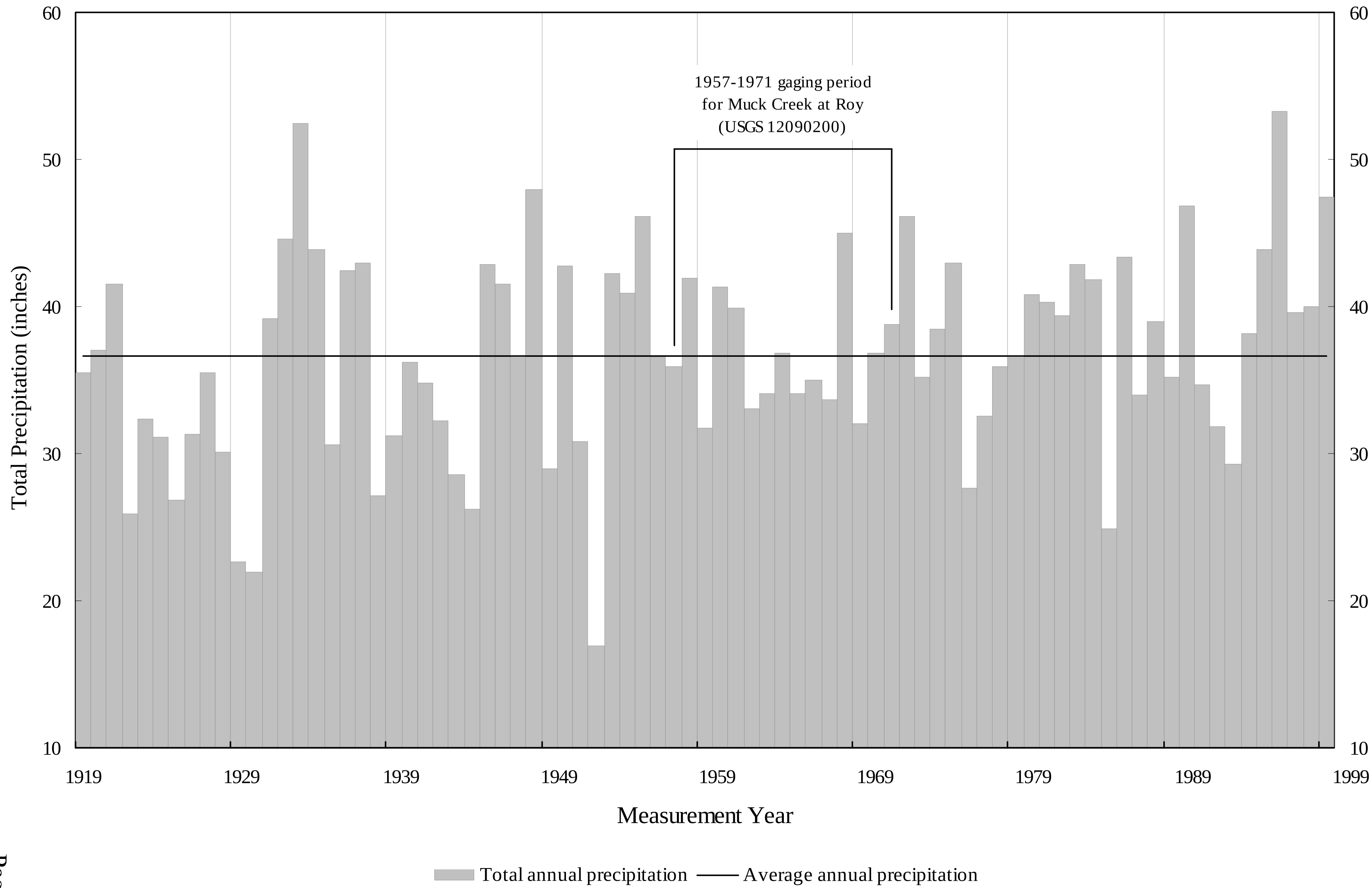


Figure 10 - Total annual precipitation at Tacoma for 1919 to 1999

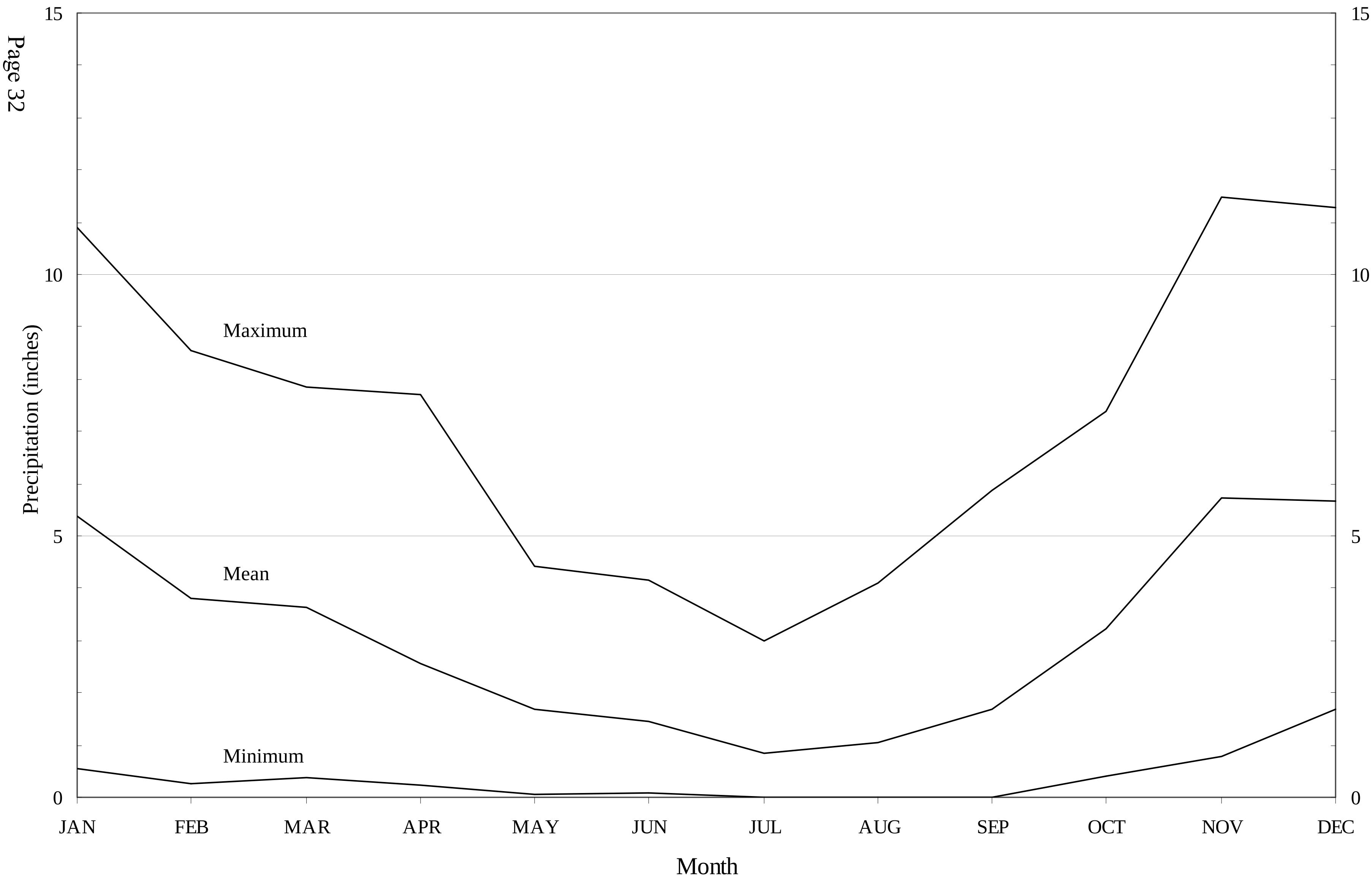


Figure 11 - Minimum, maximum, and mean of total monthly precipitation at Tacoma for 1919 to 1999

As one might expect, area streamflows are heavily influenced by both annual and seasonal precipitation patterns. Flow in Muck Creek at Roy is typically highest between December and February, and tends to lag about one month behind the seasonal precipitation peak which typically occurs between November and January. Streamflow at Roy is generally lowest between July and October, while precipitation is typically lowest between June and September (Figures 11 and 12).

Evaluation of the gaging records for Muck Creek at Roy indicates that intermittent flow conditions affected the stream over much of the 1956-71 monitoring period. The annual seven-day low flow was zero for all but three years (1961, 1963, and 1964) during this period. During the remaining years, the number of no-flow days ranged from 10 days in 1962 and 1969 to 125 days in 1957 (Figure 13). Between 1957 and 1971 flow was always present at the Roy gage throughout the 6-month period between January and June. Flow ceased at the gage, at least some of the time, during the remaining months. Periods of no flow ranged from 1.5 percent of the time in December (7 of 465 December days) to 41 percent of the time in October (191 of 465 October days). Altogether, Muck Creek was dry at the Roy gage approximately 9.1 percent of the time between 1957 and 1971. During the 1957 to 1971 monitoring period, the mean annual discharge for Muck Creek at Roy averaged 64 cubic feet per second (ft3/sec) and ranged from 28.8 ft3/sec in 1962 to 105 ft3/sec in 1961.

During the 2000-2001 monitoring period, streamflow at the Roy gage followed a similar seasonal pattern to that previously described for the 1957 to 1971 monitoring period. However flows were significantly reduced and averaged just 24.9 ft3/sec, between March 2000 and March 2001, or about 40 percent of the station mean annual discharge for water years 1957 to 1971. The reduced flows observed during 2000-01 are largely attributable to drought conditions that effected Washington State during this period. Streamflow at the Muck Creek Loveland gage during 2000-01 averaged approximately 7.9 ft3/sec and ranged from 2 to 47 ft3/sec (Appendix F). As with the Roy gage, flows in Muck Creek near Loveland were highest during the winter and early spring and lowest during the summer and fall.

Data comparisons between the two Muck Creek gages indicates that flow in Muck Creek at Roy ranged from zero to 438 ft3/sec during the 2000-01 monitoring period, while flow at the Loveland gage ranged from 2 to 47 ft3/sec (Appendix E and F). During this period the mean annual discharge at the Loveland gage comprised 32 percent of the mean annual discharge measured at Roy, yet the Loveland gage accounts for only 19 percent of the drainage area that contributes to the Roy gage. This difference in flow between upper and lower Muck Creek likely results from significant streamflow losses that occur along Muck Creek and South Creek between the two gages. Evidence to support this assertion is presented in later sections of this report.

Groundwater Recharge

Replenishment of the study area groundwater system occurs in two principal ways. Most recharge derives from local precipitation that infiltrates into the ground and percolates beyond the root zone of plants. Surface water that percolates into the ground along losing stream reaches is a secondary, but locally important, recharge source within the central watershed. In addition

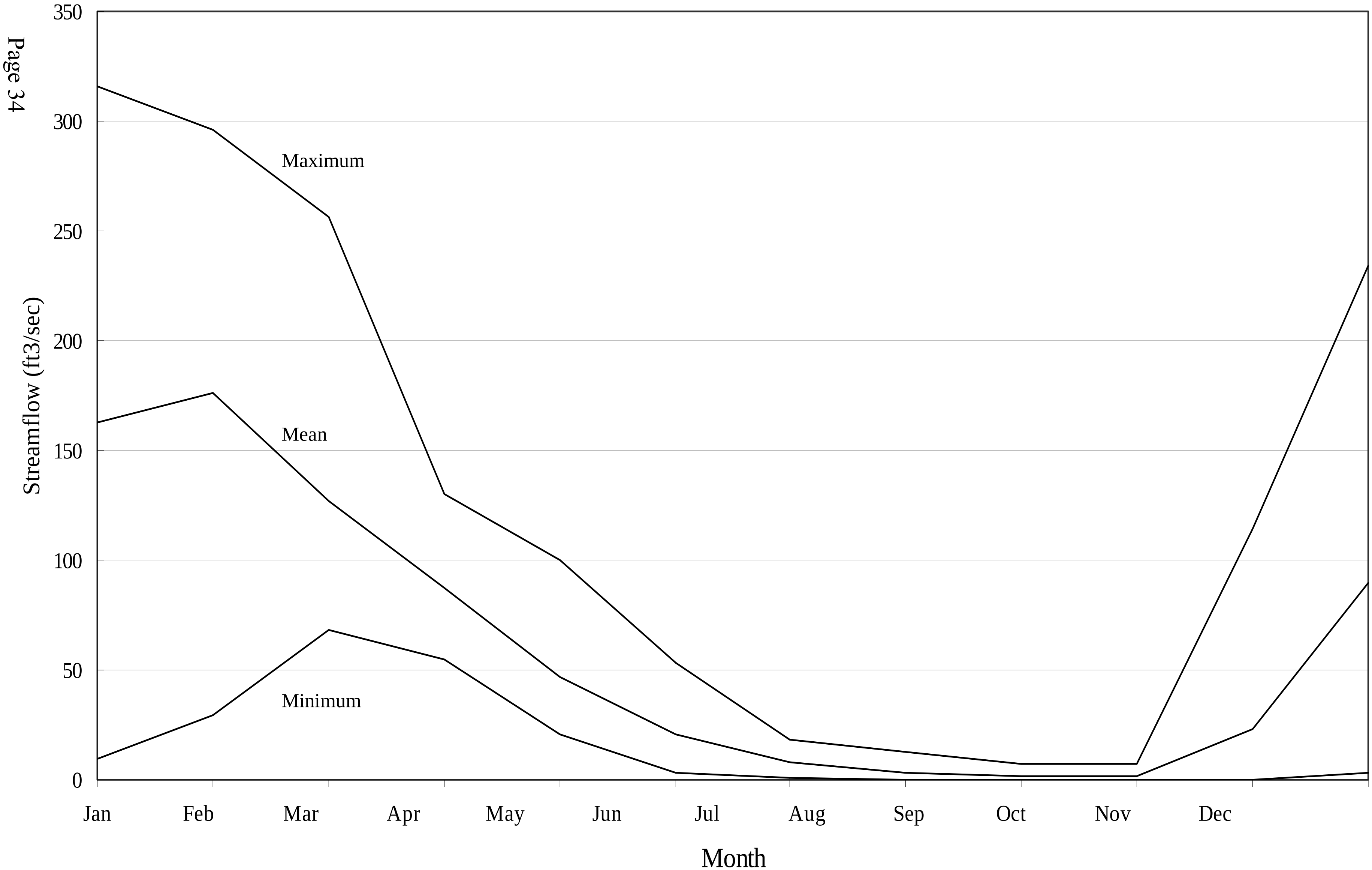


Figure 12 - Minimum, maximum, and mean of monthly mean discharge for Muck Creek at Roy (USGS 12090200) for 1956-71, 2000-2001

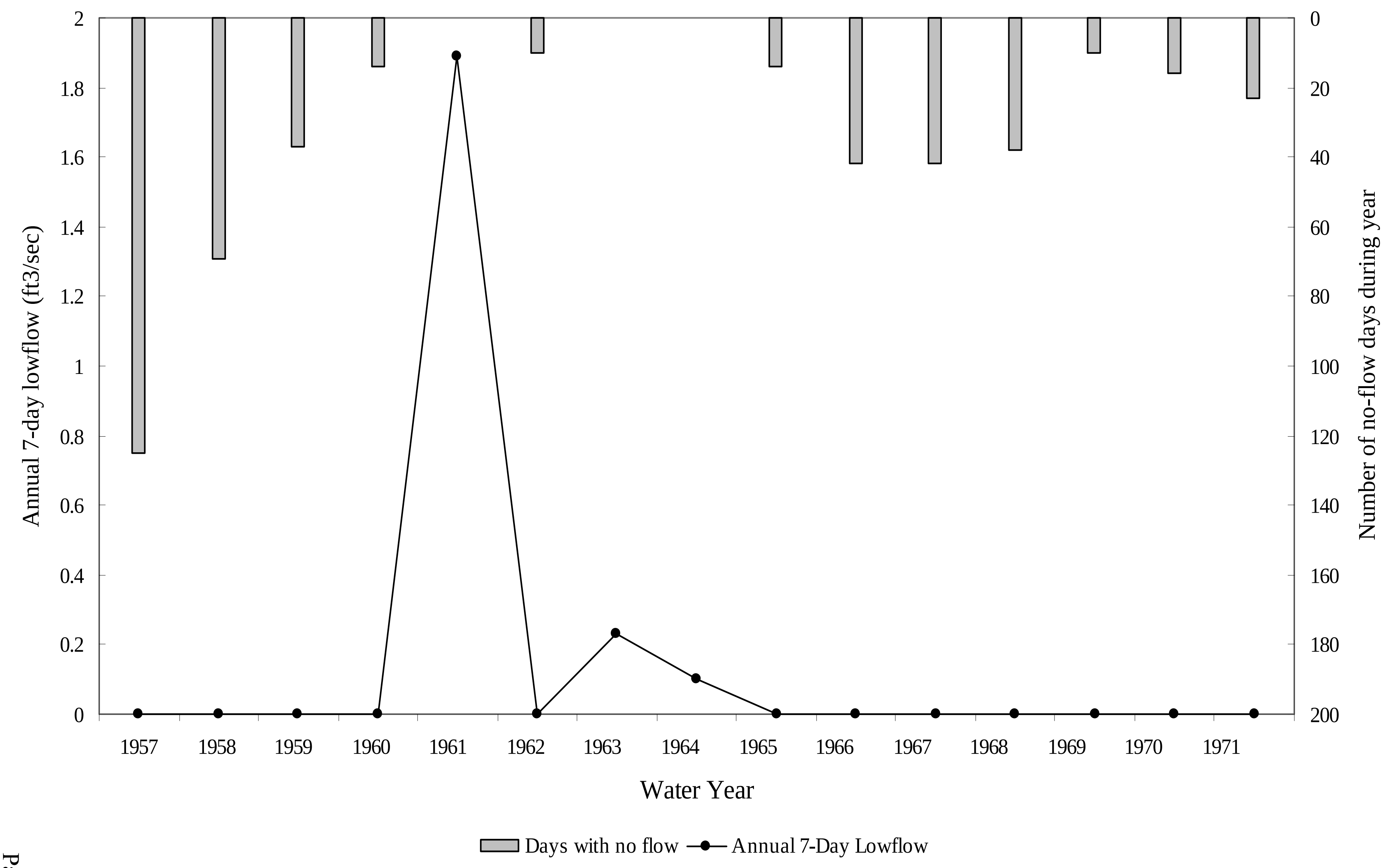


Figure 13 - Summary of annual 7-day lowflows and days of no flow for Muck Creek at Roy (USGS 12090200) for water years 1957-71

to these primary recharge mechanisms, groundwater replenishment may occur through septic discharge of local and "imported" water that enters the basin through public water systems, bottled beverages, and food products. The volume of water imported to the basin via these sources is thought to be negligible relative to the volume derived from precipitation and stream loss, and was not considered during this evaluation.

Recharge from precipitation occurs throughout the watershed, except for small areas that are covered by impervious surfaces such as paved roads, parking lots, and buildings, or those areas where groundwater discharges at land surface. Because the study area is not sewered, most precipitation that falls on impervious surfaces is merely rerouted or diverted to on-site detention facilities or nearby drainage ditches, where it ultimately contributes to recharge.

Recharge from precipitation was estimated for the study area using regression equations developed by Woodward et al. (1995) for King County. The equations estimate recharge based on the surficial geology, precipitation, soil characteristics, and predominant land cover (grass or forest) for an area. Application of the equations to the Muck Creek watershed is appropriate, given the proximity and similarity of the two areas.

For estimation purposes, the study area's surficial hydrogeologic units were grouped into "till" or "outwash" polygons based on their dominant lithologic and hydrologic characteristics. As defined, the till and outwash polygons correspond with the distribution of till (Qvt) and outwash (Qvr and Qc1) shown on Figure 7. GIS techniques were then used to superimpose contours of average annual precipitation over the till/outwash polygons. Recharge values for each polygon were then computed, based on the relationships shown in Figure 14. Based on this evaluation, recharge from precipitation averages approximately 21 inches or 108,000 acre feet per year, and ranges from approximately 17 to 28 inches depending on location (Figure 15).

Recharge from stream loss was estimated using streamflow records for Muck Creek near Loveland, specific conductance information for Muck Creek and South Creek, and recent stream seepage evaluations conducted during this study. The streamflow records for Muck Creek near Loveland (Figure 5, site M22 and Appendix F) provide a conservative (minimum) estimate of the potential recharge from stream loss that occurred within the central intermittent reach of Muck Creek during 2000-01. Measurements made during this study indicate that Muck Creek was dry at Highway 507 (Figure 5, site M11 and Appendix G) for all, but perhaps a few, days during the first year of data collection at the Loveland gage (March 28, 2000 to March 5, 2001). Highway 507 lies downstream of the Loveland gage near the downstream extent of Muck Creek's central intermittent reach. Since the combined flows of Muck Creek and South Creek did not reach Highway 507 during this period, it can be inferred that the minimum stream loss within this reach must have been greater than 7.9 ft3/sec (5,720 acre feet per year), the average streamflow measured at Muck Creek near Loveland.

The above estimate does not account for seepage losses that occur seasonally along South Creek as it traverses the Fort Lewis prairie prior to joining with Muck Creek. South Creek was not gaged during this study, so there is no direct way to estimate this loss. Indirect estimates of

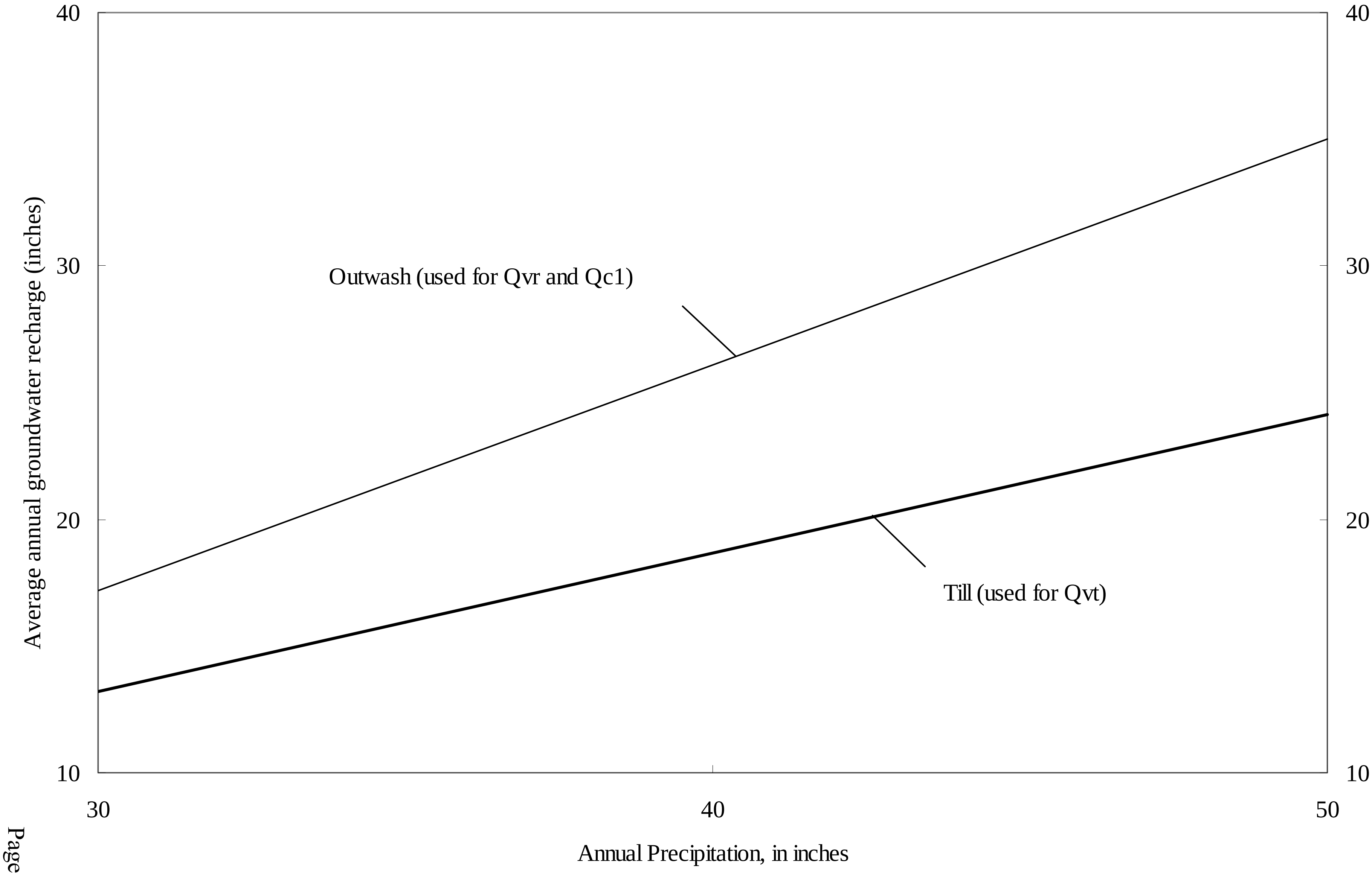


Figure 14 - Precipitation/recharge relationship used to estimate recharge for the study area (after Woodward and others, 1995)

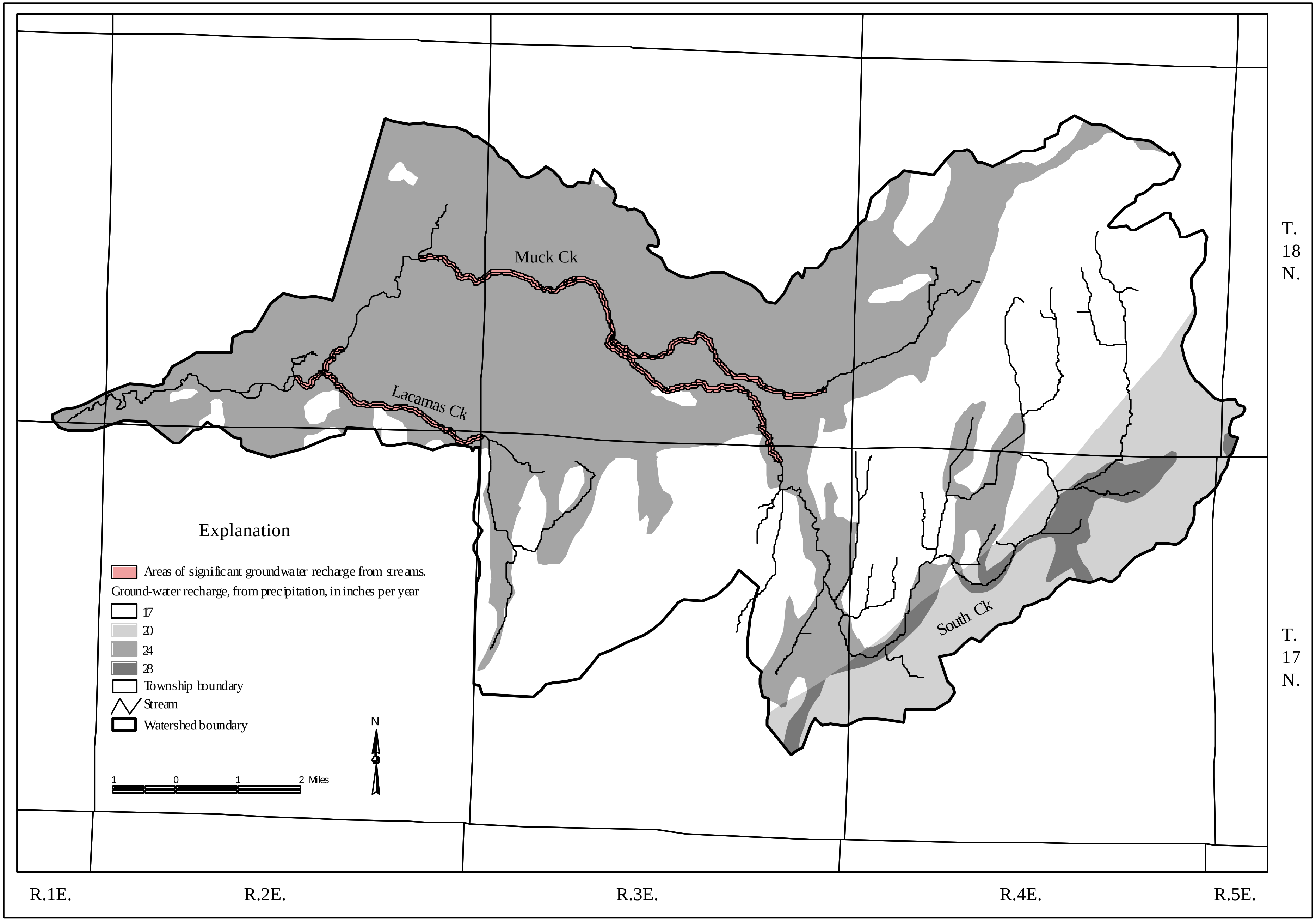


Figure 15 - Distribution of average annual recharge from precipitation, for the Muck Creek Watershed

stream loss for South Creek were developed from a simplistic mixing analysis using stream specific conductance[2] measurements for South Creek at station S3 and Muck Creek at stations M18 and M22 (Figure 5). Stations S3 and M22 represent the specific conductance of South Creek and Muck Creek proper, while station M18 represents the specific conductance that results after South Creek and Muck Creek join. If one knows the specific conductance of a mixed water source (site M18 in this case) and the inputs that comprise the mixed water (sites S3 and M22), one can estimate the relative volumetric ratios of the two inputs using the following equation:

$CM = X*Ca+(1-X)*Cb$ which yields $X=(Cb-Cm)/(Cb-Ca)$

Where Cm = the constituent concentration of the mixed water
Ca = the constituent concentration of stream A
Cb = the constituent concentration of stream B
X = the fraction of stream A in the mixed water
$1-X$ = the fraction of stream B in the mixed water

Incorporating specific conductance values for sites S3, M22, and M18 into the above equation indicates that South Creek's contribution to the total flow in Muck Creek at site M18 ranged from 40 percent in May 2000 to about 80 percent in February 2001 (Figure 16). This latter value compares favorably with the February 2001 seepage evaluation, when South Creek contributed roughly 75 percent of the flow (approximately 21 of 28 ft3/sec) measured in Muck Creek at site M17 (Figure 6). Based on this evaluation, South Creek contributed on average, approximately 60 percent of the total flow measured in Muck Creek (at site M18) during the wet season (late fall to early spring) (Figure 16). If one assumes comparable rates of seepage loss from South Creek and Muck Creek as they traverse the Fort Lewis prairie, then the combined seepage loss for both streams was probably on the order of 20 ft3/sec, or approximately 14,480 acre feet, during the study period.

If one accounts for drought effects during 2000-01, which reduced Muck Creek's streamflow by 60 percent at Roy relative to the 1957-71 station average, then seepage losses through the central reach of Muck Creek could approach 22,000 acre feet or more annually.

Combining the above estimates for stream loss and precipitation-derived recharge yields a total recharge estimate of approximately 130,000 acre feet per year for the watershed. Approximately 17 percent of this total is derived from stream leakage, with the remainder from direct precipitation on the land surface.

Groundwater Fluctuation and Movement

Groundwater levels naturally fluctuate in response to seasonal and long-term variations in precipitation, recharge, and groundwater discharge (both natural and human induced). Periodic measurement of well-water levels is the only practical means of evaluating these changes. The

[2] Specific conductance is a measure of waters ability to conduct electricity and indirectly indicates both the concentration and charge of dissolved ions present in water.

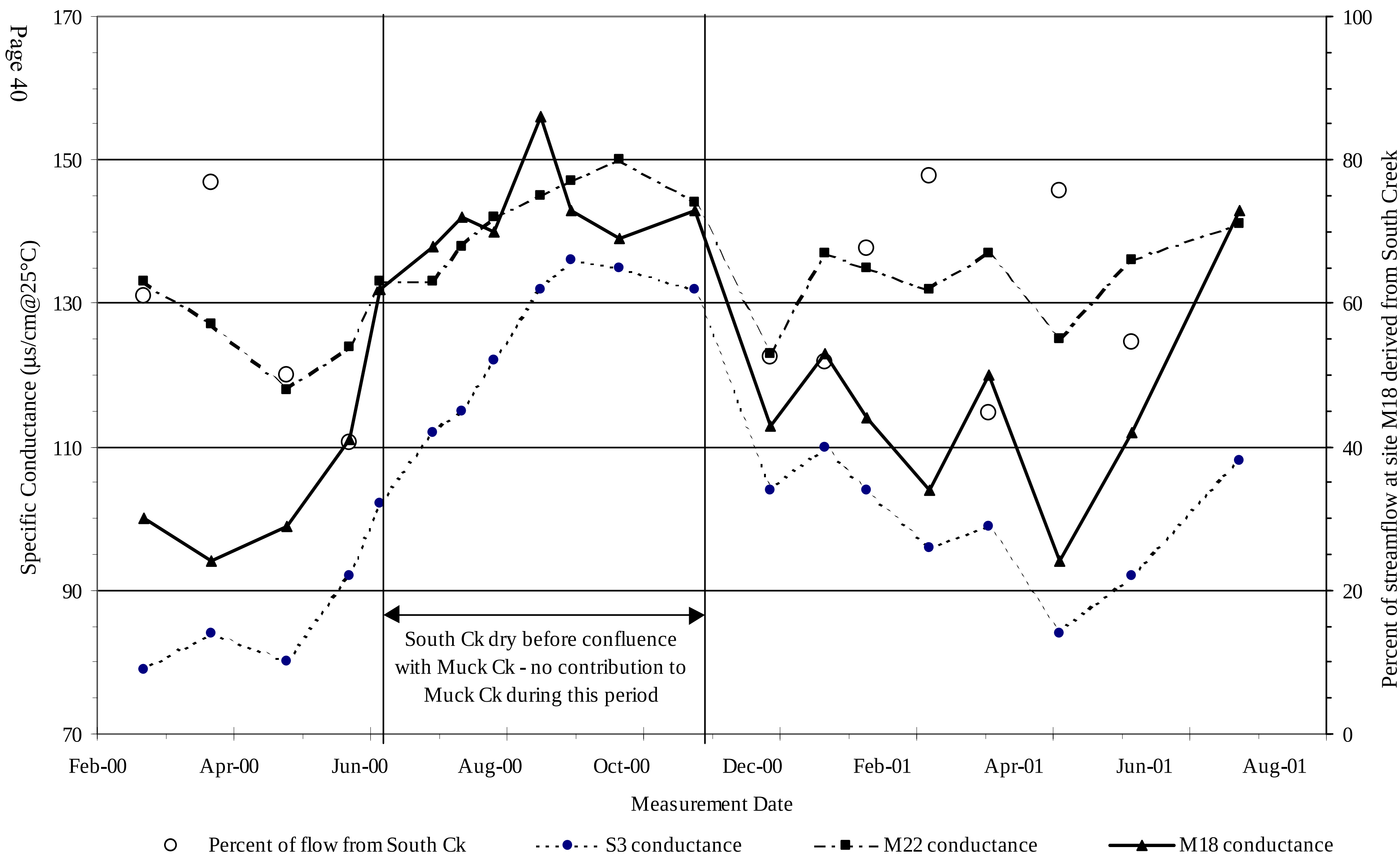


Figure 16 - Stream specific conductance at sites S3, M18, and M22 and estimated streamflow contribution from South Creek to Muck Creek at site M18

observation-well network for this study consisted of 15 private domestic and/or irrigation wells ranging from 15 to 220 feet deep. The well network was monitored monthly between May 2000 and May 2001 for water level, temperature, and specific conductance (Figure 17 and Appendix H). Two wells, AFC086 and AFC094, have water-level histories dating back to the early-to-mid 1940s and were used to evaluate long-term water-level trends (Figure 18). Construction details for the observation wells are shown in Appendix A.

For the wells monitored, seasonal fluctuations ranged from a few feet in wells AFC091, AFC093, and AFC098 to more than 16 feet in well AFC089. Wells AFC096 and AFC097 exhibited even larger variations, although much of their fluctuation resulted from heavy seasonal pumping for irrigation and is not directly comparable to the other wells. The small amount of variation noted in wells AFC091, AFC093, and AFC098 likely results from their locations within groundwater discharge areas, where water levels tend to fluctuate over a relatively small range.

Water levels in unit Qvr were typically highest between March and April and lowest during September and October. Water levels in aquifer Qc1 were highest between March and April and lowest between September and November, while those in aquifer Qc3 were highest between April and May and lowest between July and October. Several wells never fully recovered between March 2000 and March 2001. This is likely due to the drought that affected Washington State during 2000-2001. Wells AFC086 and AFC094 deviated slightly from their traditional long-term patterns by having seasonal highs that were lower than average during this period (Figure 18). Neither well exhibits a sustained upward or downward trend in water levels which suggests that groundwater use in their vicinity has not measurably impacted area water levels.

Figure 19 shows generalized potentiometric contours and inferred groundwater flow directions for the study area. It was prepared using water-level and altitude data from inventoried springs, and wells less than 125 feet deep. The water-level data were derived from several sources, including driller reported measurements at the time of well construction, and more recent measurements by Ecology, the USGS, and consultants. Well and spring altitudes were determined from 1/24,000 scale topographic maps and are considered accurate to +- ½ the map contour interval, or about 10 feet in most cases. When multiple water levels were available for a well, preference was given to measurements made between June and September. As such, Figure 19 provides a generalized depiction of "dry season" groundwater conditions for the study area. It does not represent conditions within a single hydrogeologic unit at a specific point in time.

Groundwater within the study area generally flows from upland recharge areas in the eastern watershed toward topographically lower points in the western watershed and points beyond (Figure 19). Localized deviations from this general trend occur where water from the South Creek upland moves northwest and discharges along the well-defined seepage face that defines the southern margin of the Muck Creek channel. South-to-southwest flow components are also apparent in upper South Creek where groundwater follows the general trend of South Creek. Horizontal flow at any point in the study area follows a path that is approximately perpendicular to the potentiometric contours in the direction of decreasing altitude.

Surface water and Groundwater Interchange

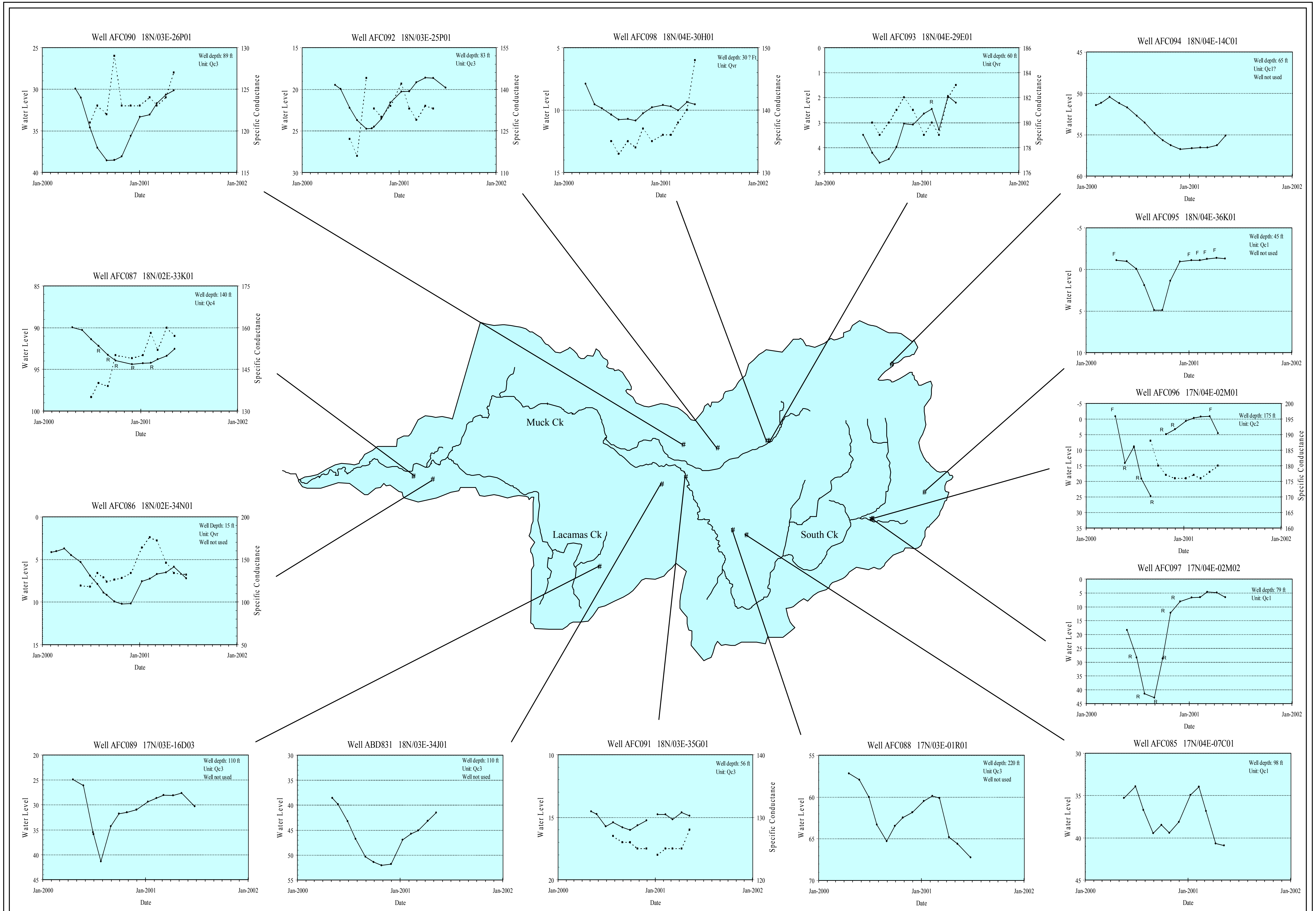
The direct interchange of water between streams and groundwater occurs in three basic ways. Streams can gain water from groundwater inflow through their streambed, they can lose water through their streambed to groundwater, or they may do both, gaining in some reaches and losing in others (Winter et al., 1998). For groundwater to enter a stream directly, two conditions must be present. There must first be a saturated connection between the stream and groundwater and, secondly, the groundwater must lie at a higher altitude (have a higher potential head) than the stream surface (Figure 20A). The only condition required for water to leave a stream is that the stream surface lie at a higher altitude than groundwater (Figure 20B and C). Stream loss can occur regardless of whether a stream and groundwater are connected by saturated materials or are separated by a zone of unsaturated material (Figure 20C).

When a stream and groundwater are connected by saturated materials, the rate of interchange depends on the vertical hydraulic conductivity of the streambed and the hydraulic gradient between the stream and groundwater. When a stream is disconnected from groundwater by an unsaturated zone, the rate of stream loss depends on the stream depth and the unsaturated vertical hydraulic conductivity of the streambed material.

Stream and groundwater interchange is further complicated by natural heterogeneity within streambed sediments, which can influence both the location and rate of water interchange. Lenses or beds of coarse material within finer grained streambed deposits can preferentially transmit and discharge groundwater to streams. Where streams are perched above the water table, these geologic conditions can result in reaches that lose significant flow relative to adjacent reaches that are underlain by finer grained deposits.

For this study, two common field techniques were used to evaluate stream and groundwater interchange. Instream piezometers were installed within Muck, South, and Lacamas creeks to define the vertical hydraulic gradient and direction of water interchange (into or out of the stream) at specific points within the study area. Stream seepage evaluations were used to estimate the volume and distribution of streamflow gains or loses across larger stream reaches. The results of these evaluations are shown in Figures 6 and 21 and Appendix B.

Fourteen of 19 piezometers monitored during this study indicated losing conditions, two indicated gaining conditions, two indicated both gaining and losing conditions depending on the period evaluated, and one showed no discernable interchange. Examples of these relationships are described below for a typical gaining, losing, and seasonally variable piezometer.



Explanation

F: well flowing
R: well recently pumped
Specific Conductance (us/cm@25 deg C)
Water Level (feet below land surface)

Figure 17 - Water level and specific conductance measurements for monthly observation wells in the Muck Creek study area

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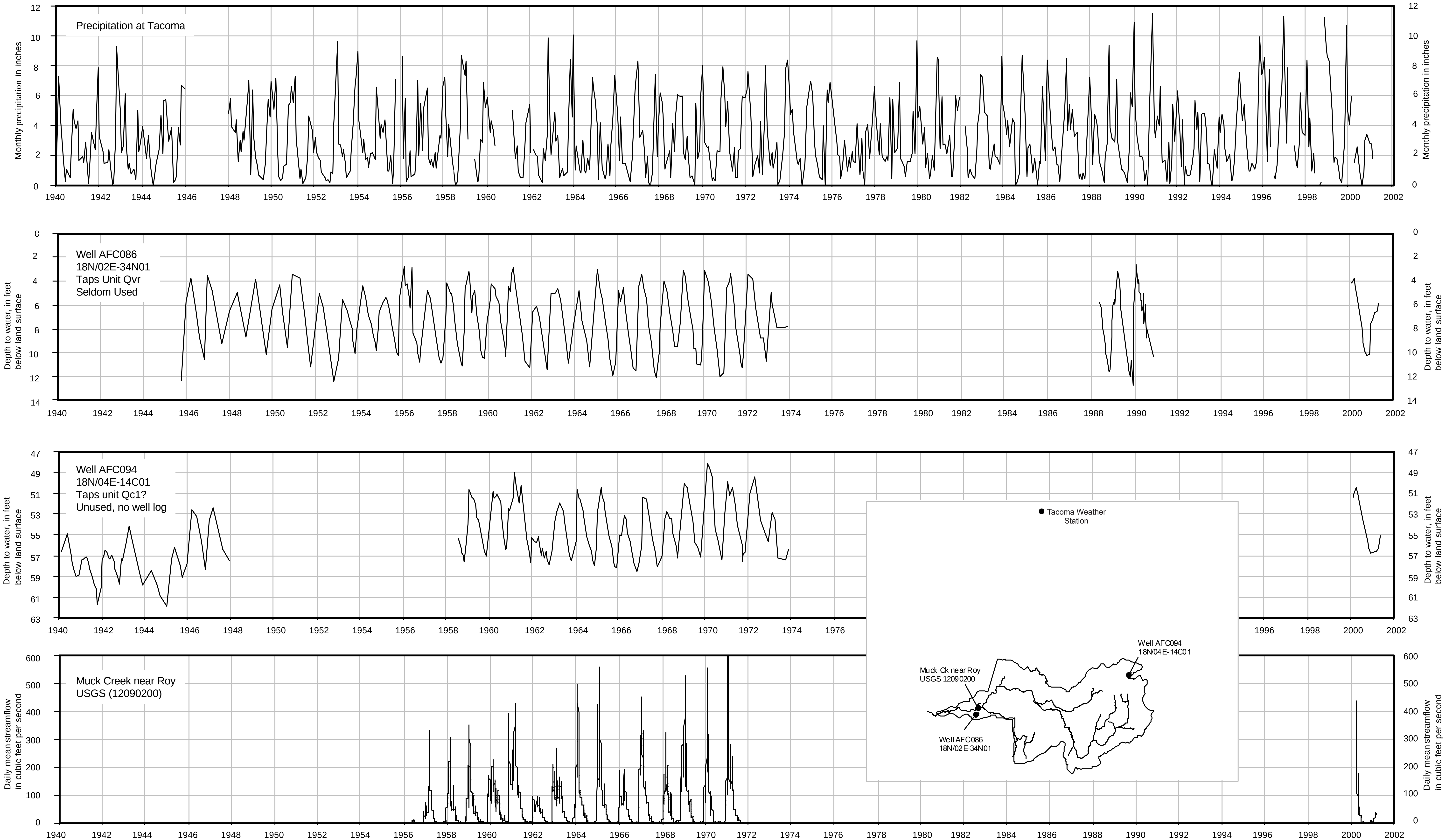

Note: Data plotted in calendar years (Jan-Jan)

Figure 18 - Precipitation at Tacoma, depth to water in wells AFC086 and AFC094, and streamflow for Muck Ck near Roy for 1940-2001

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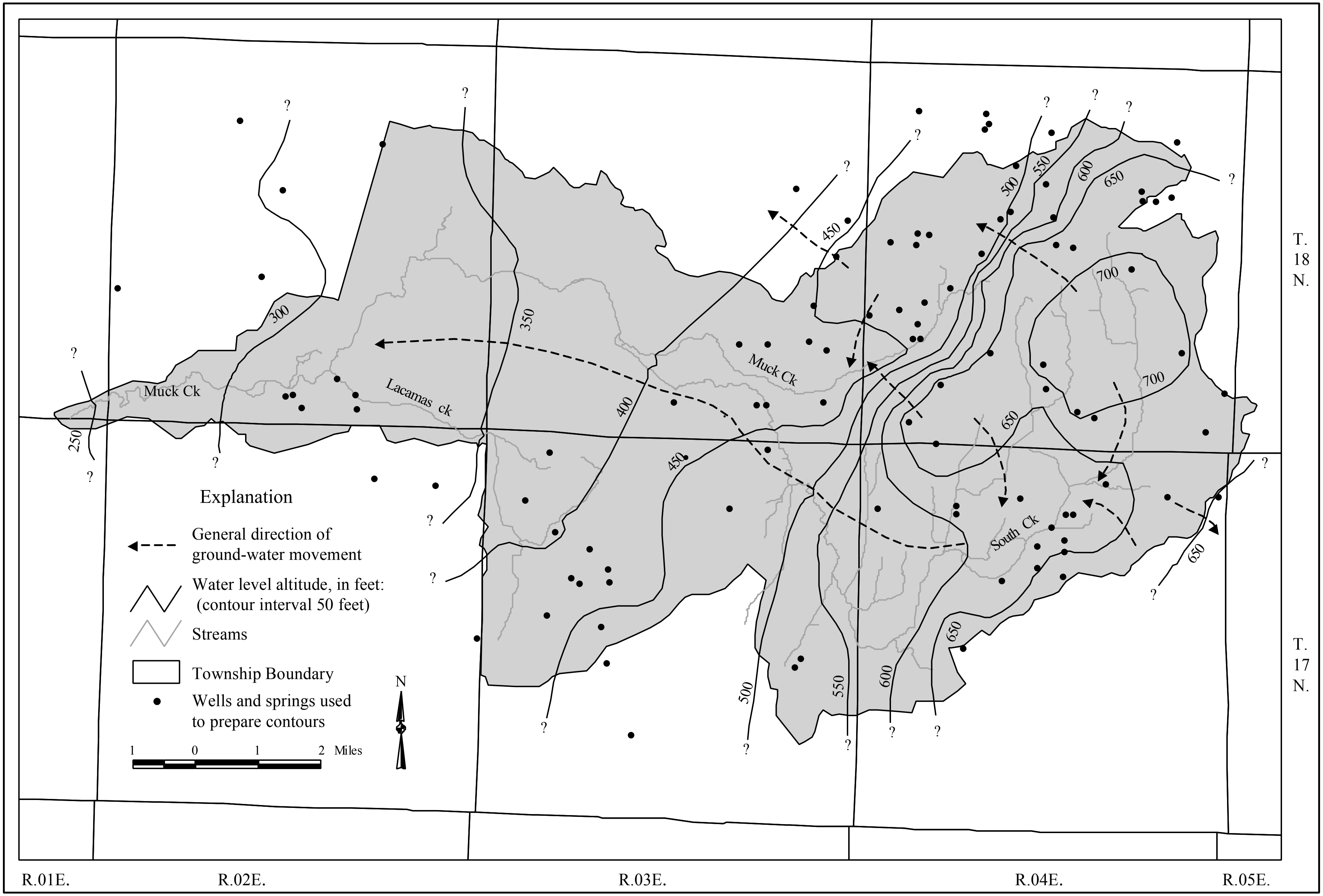


Figure 19 - Generalized water-level altitude and groundwater flow direction within the Muck Creek watershed

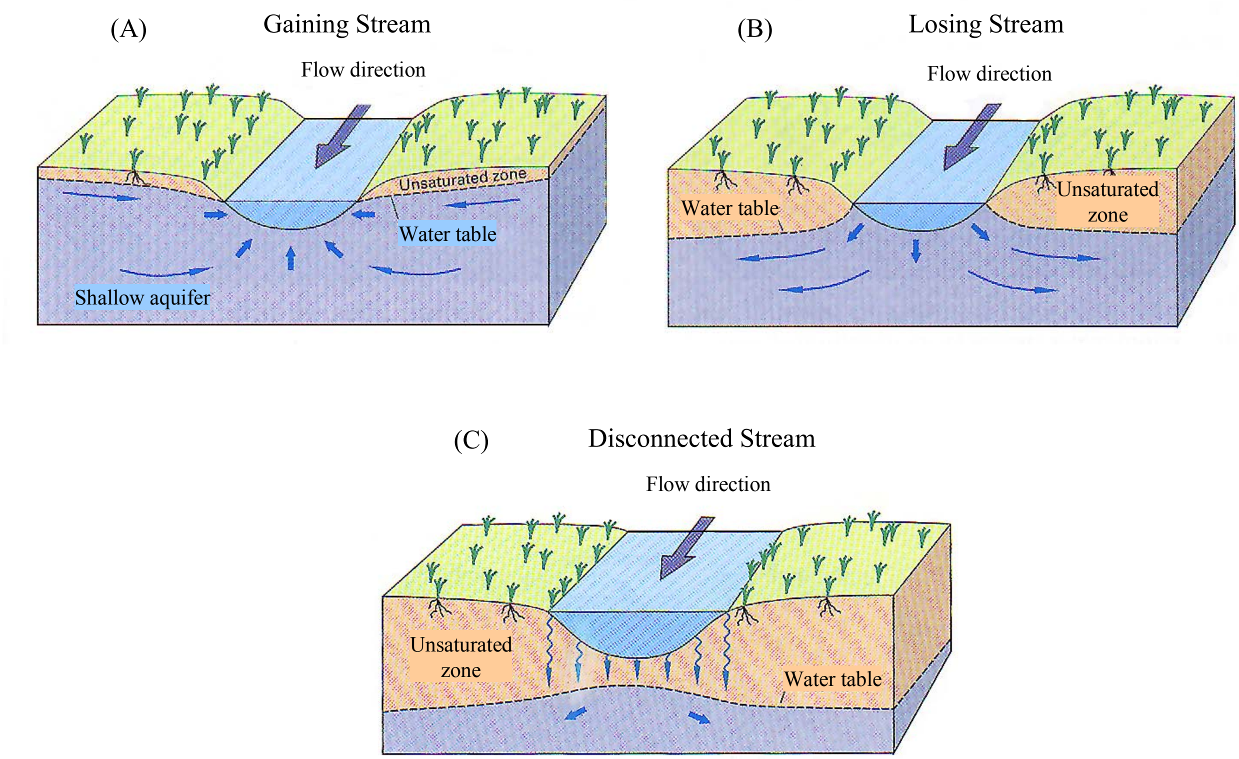


Figure 20 - Generalized depiction of stream and ground-water interchange within gaining, losing, and disconnected stream reaches (after Winter et al, 1998)

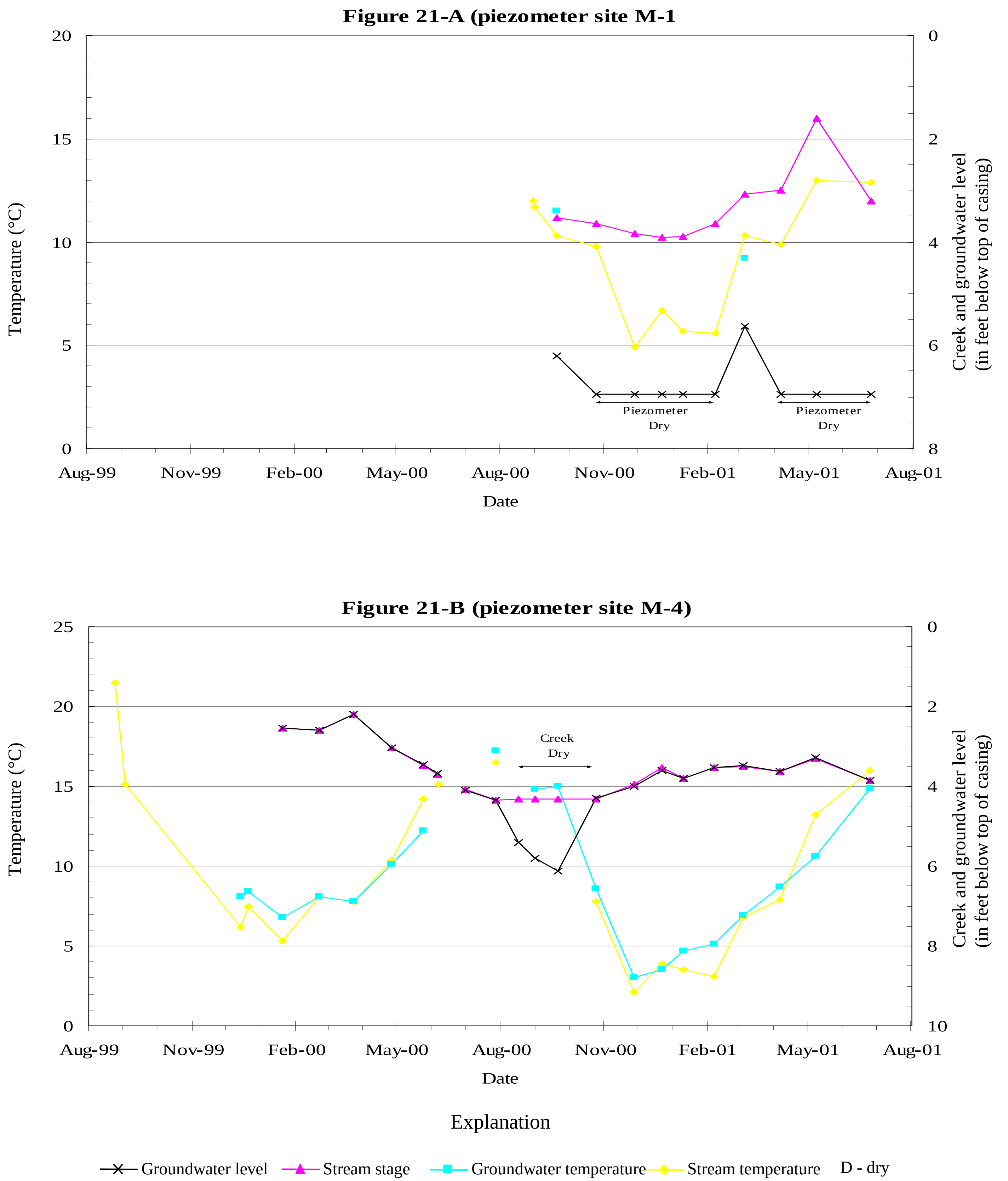
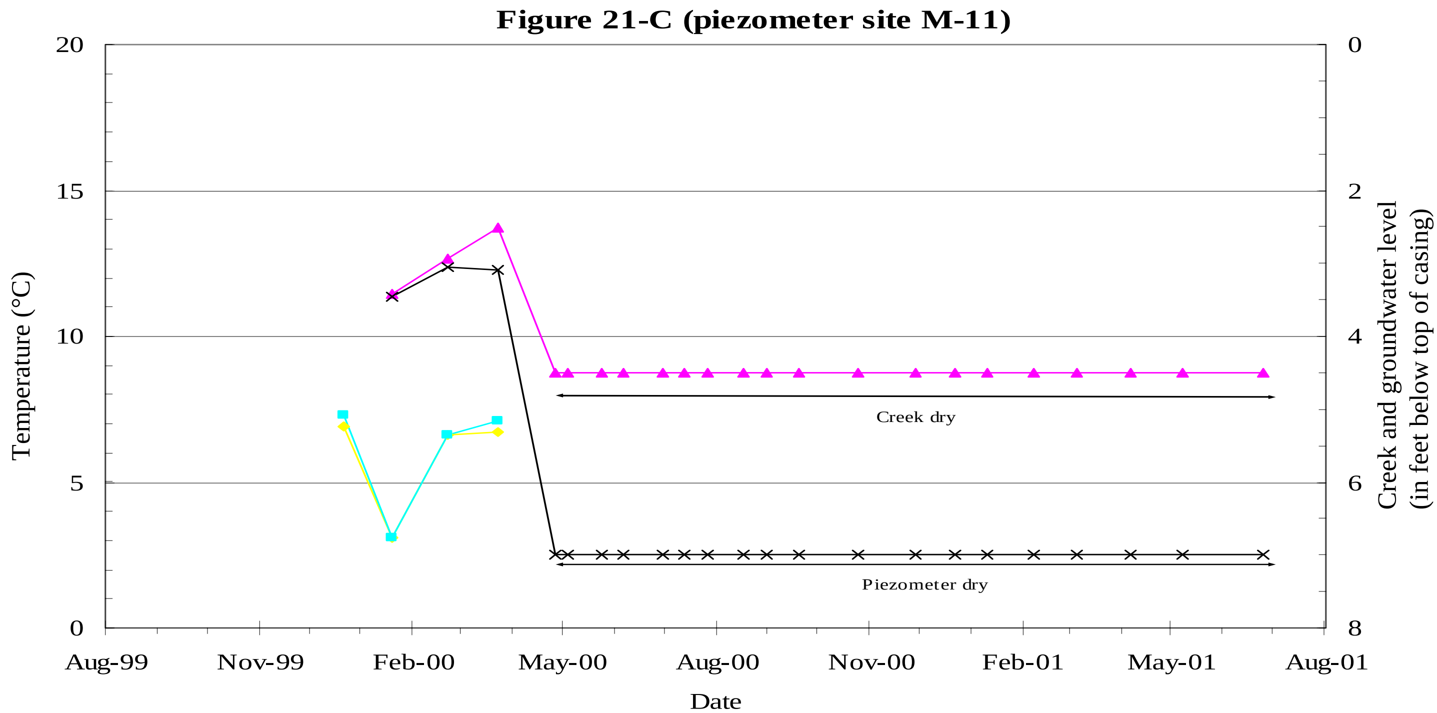


Figure 21 - Comparison of surface water and groundwater conditions at instream piezometer sites within the Muck Creek Watershed (See Figure 5 for site locations)



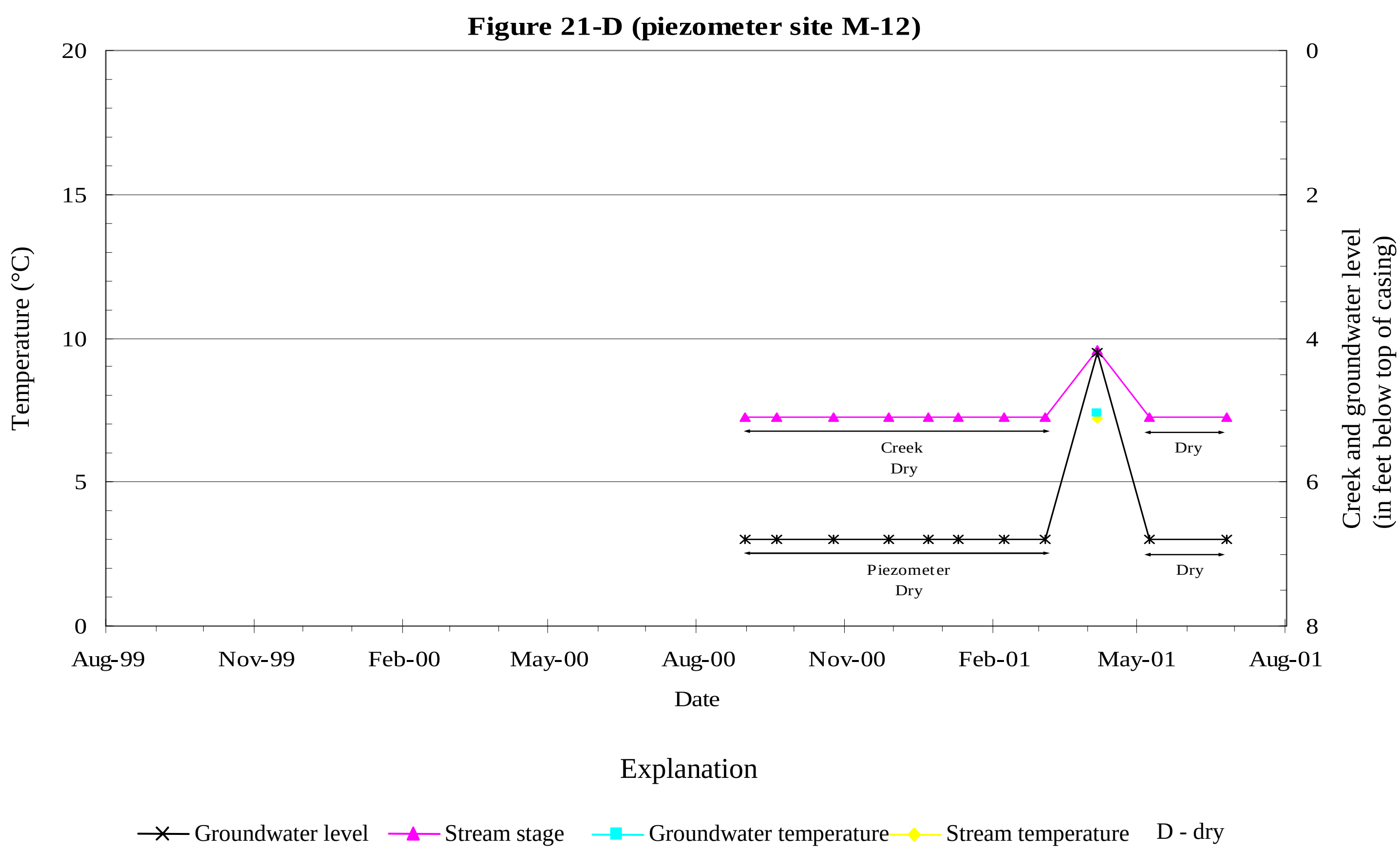
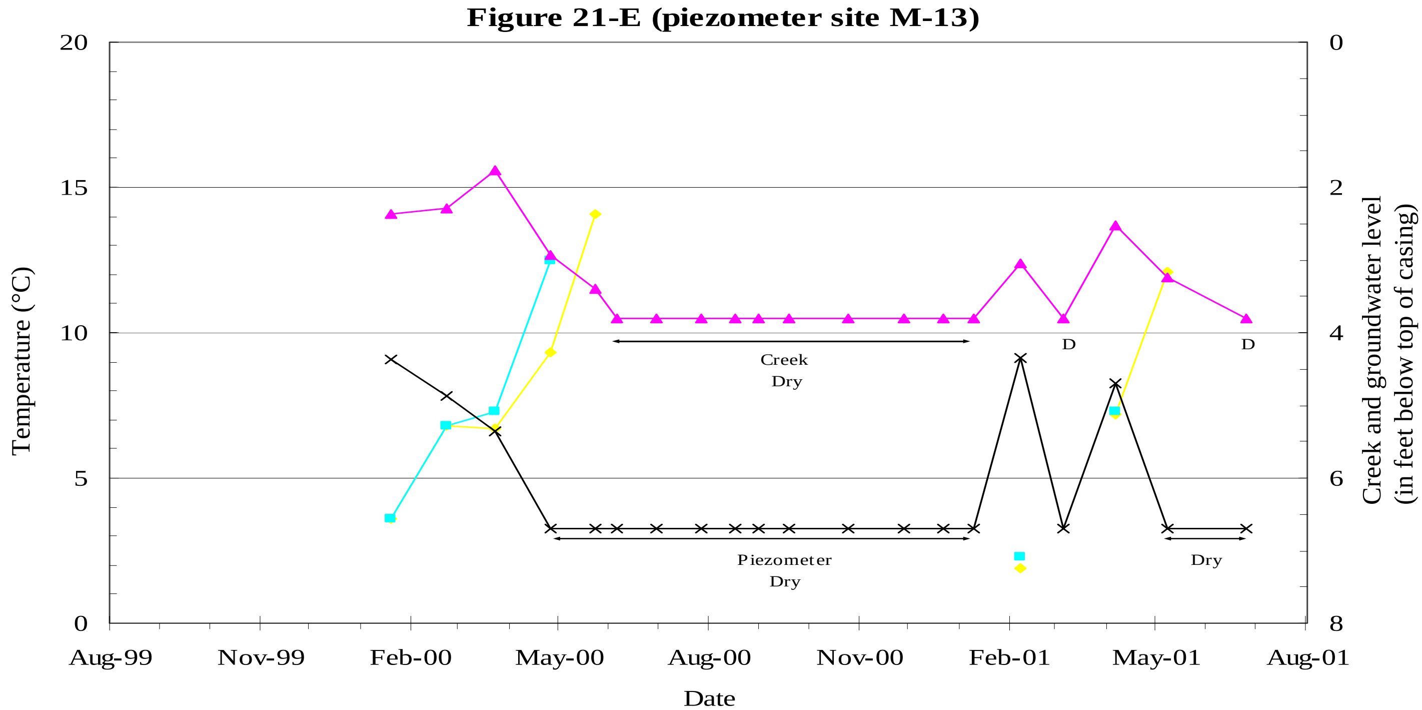
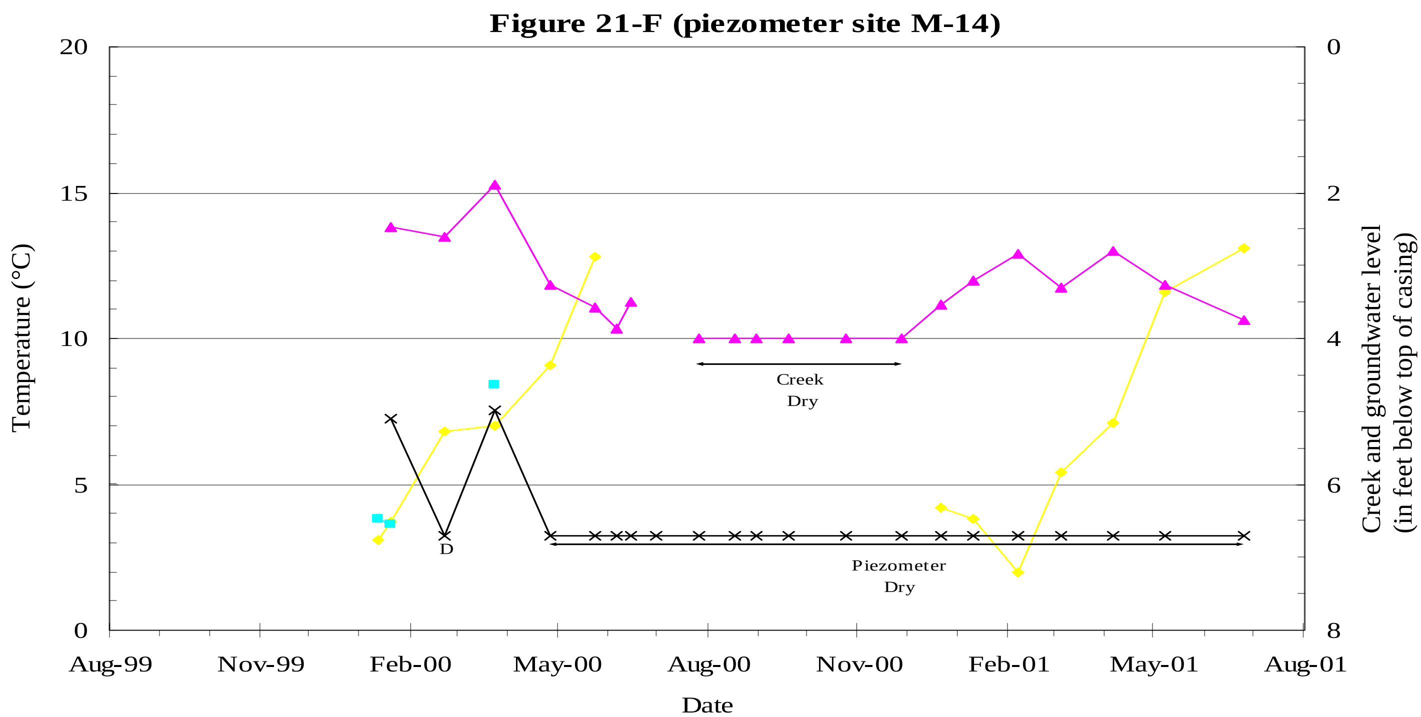


Figure 21 - (Continued) (See Figure 5 for site locations)





Explanation

Groundwater level — Stream stage — Groundwater temperature — Stream temperature — D - dry

Figure 21 - (Continued) (See Figure 5 for site locations)

Figure 21-G (piezometer site M-15)

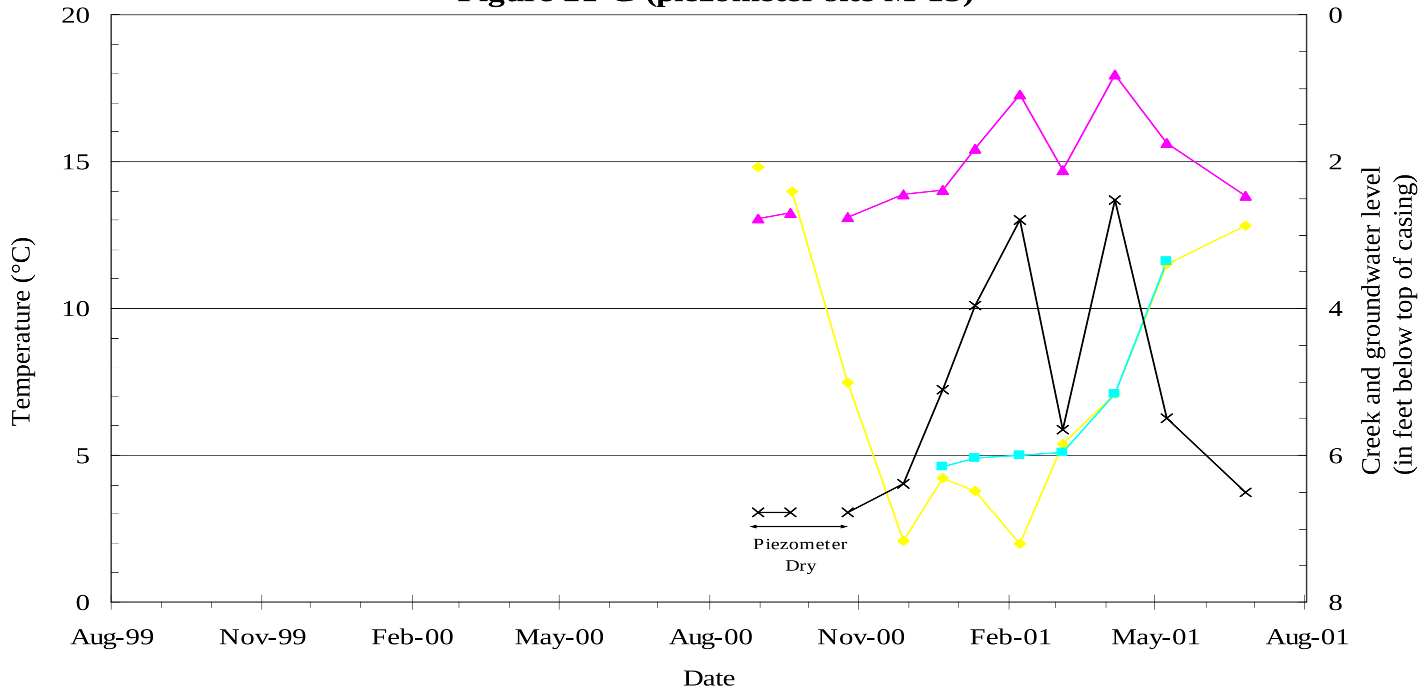
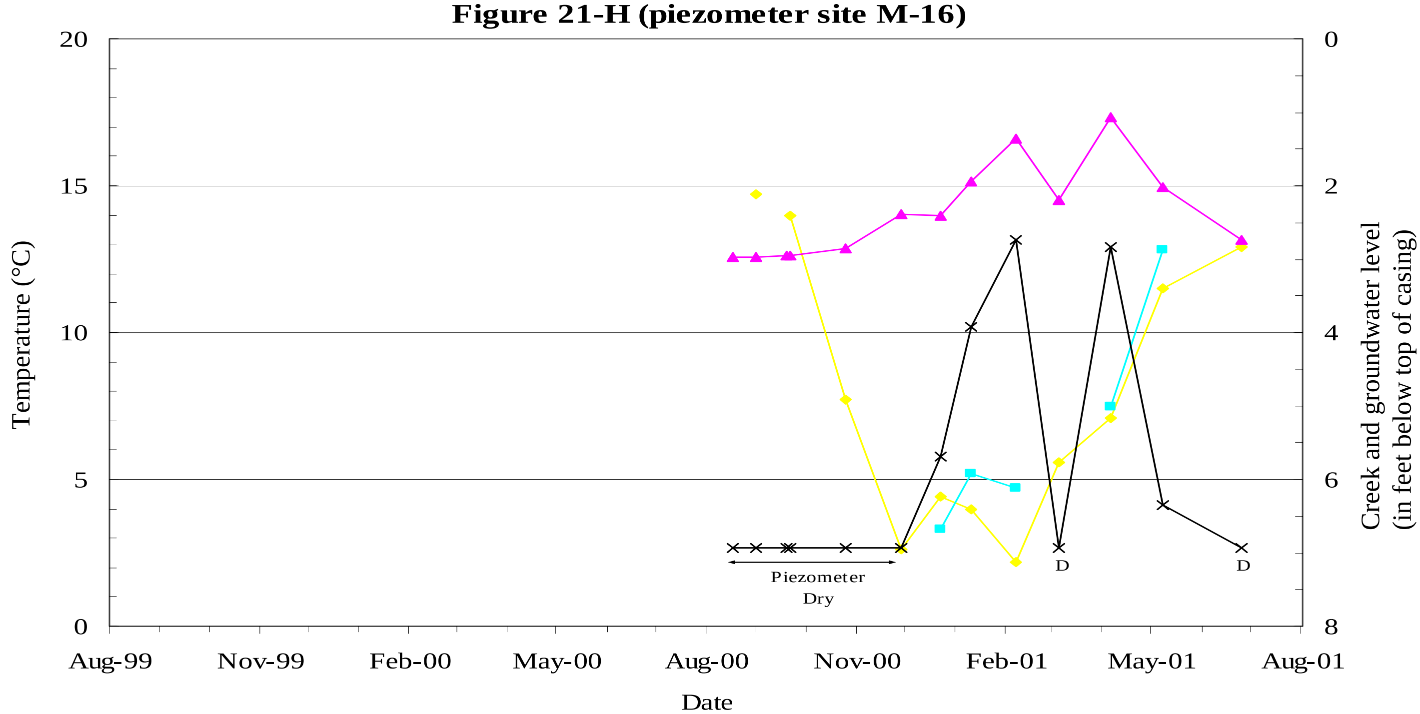


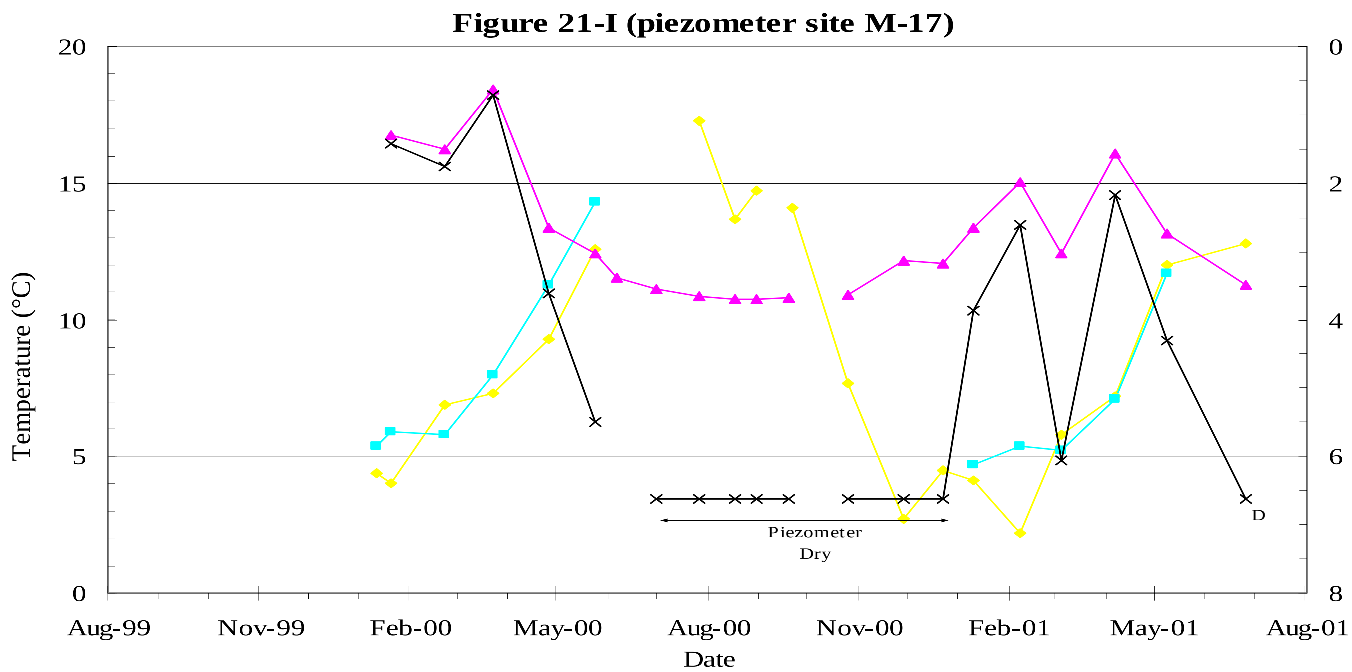
Figure 21-H (piezometer site M-16)

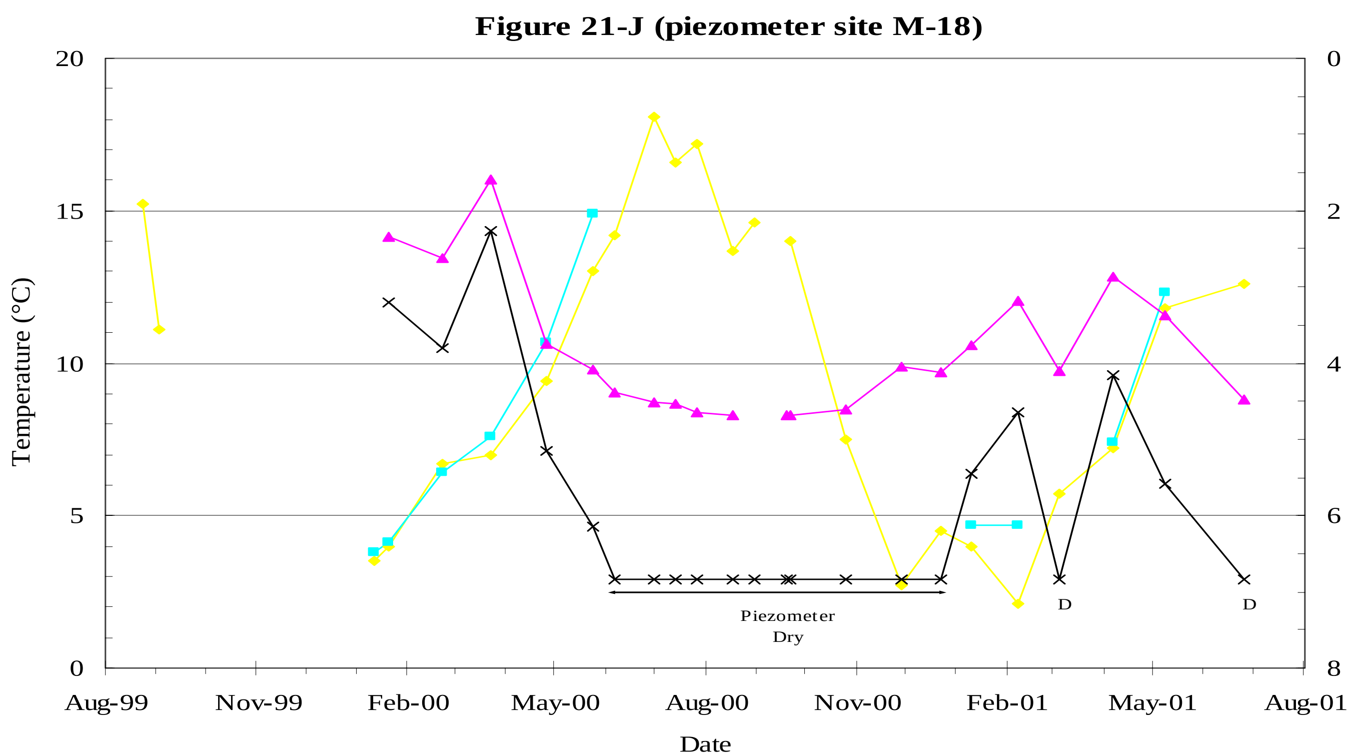


Explanation

Groundwater level — Stream stage — Groundwater temperature — Stream temperature — D - dry

Figure 21 - (Continued) (See Figure 5 for site locations)





Explanation

Groundwater level — Stream stage — Groundwater temperature — Stream temperature — D - dry

Figure 21 - (Continued) (See Figure 5 for site locations)

Figure 21-K (piezometer site M-19)

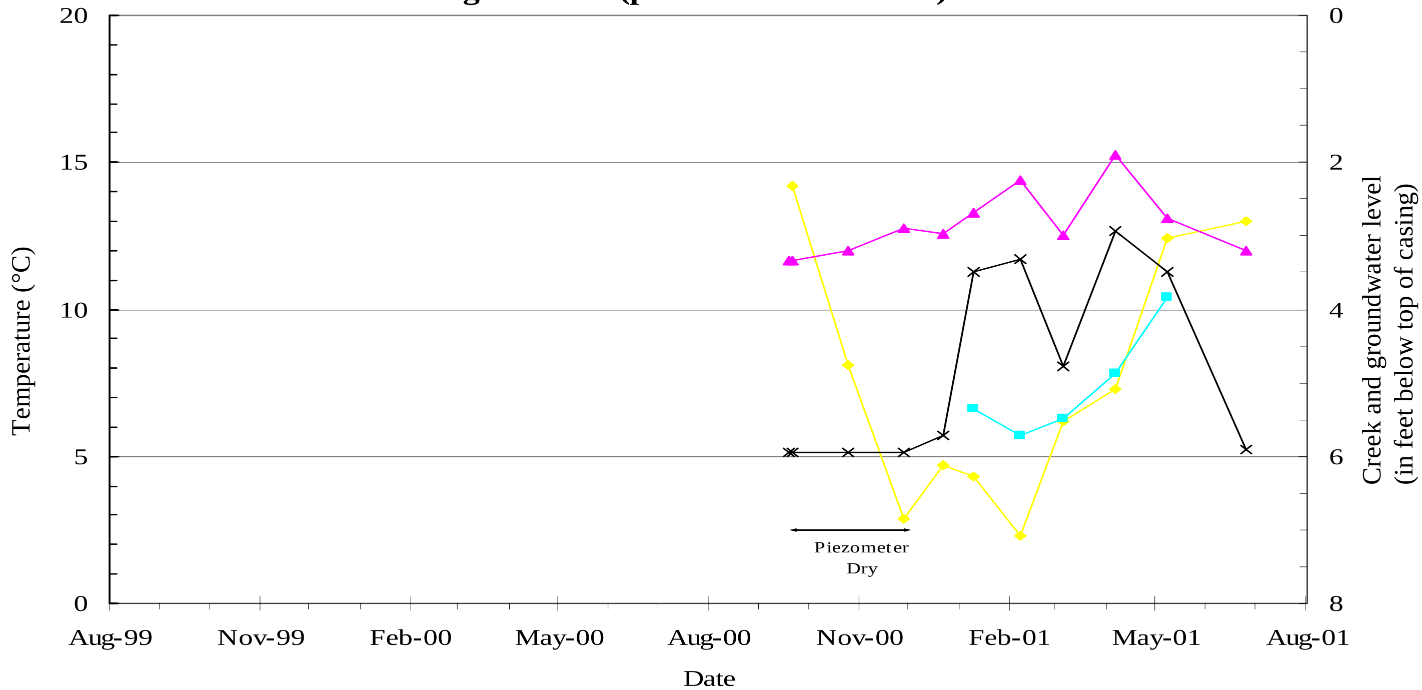
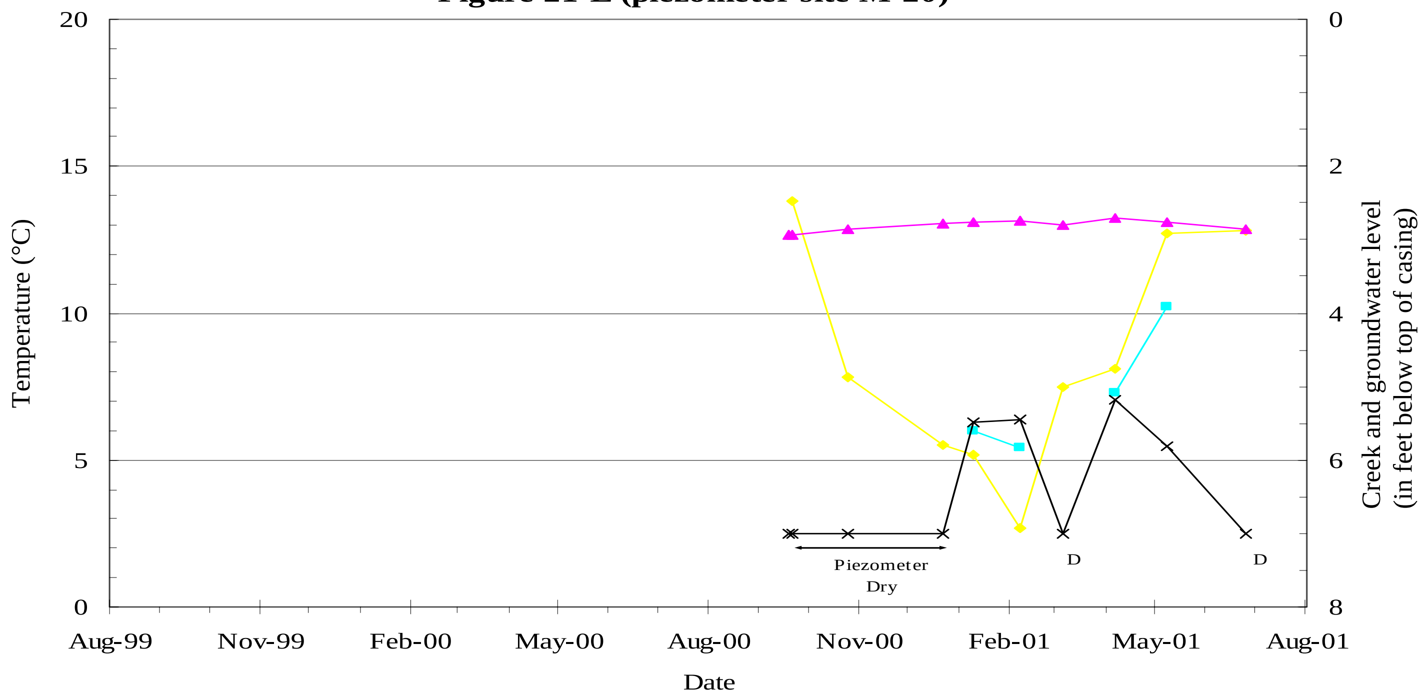


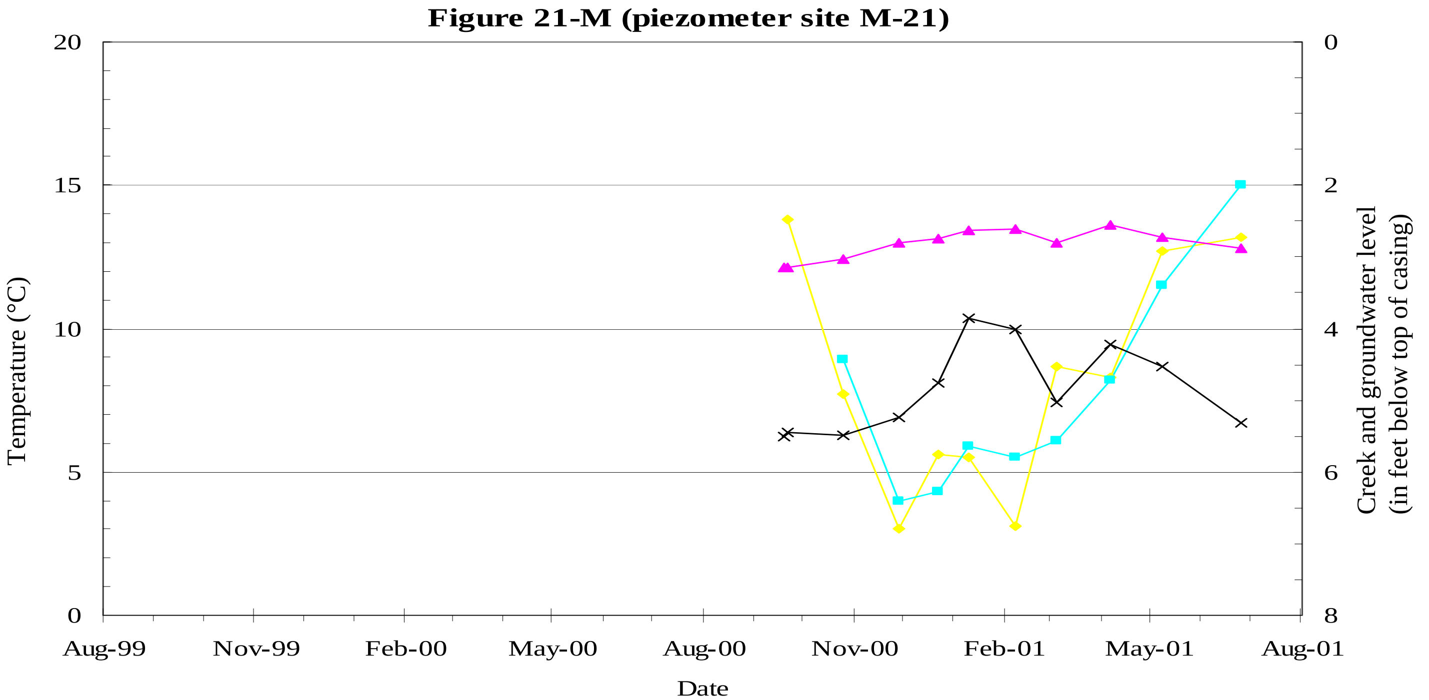
Figure 21-L (piezometer site M-20)

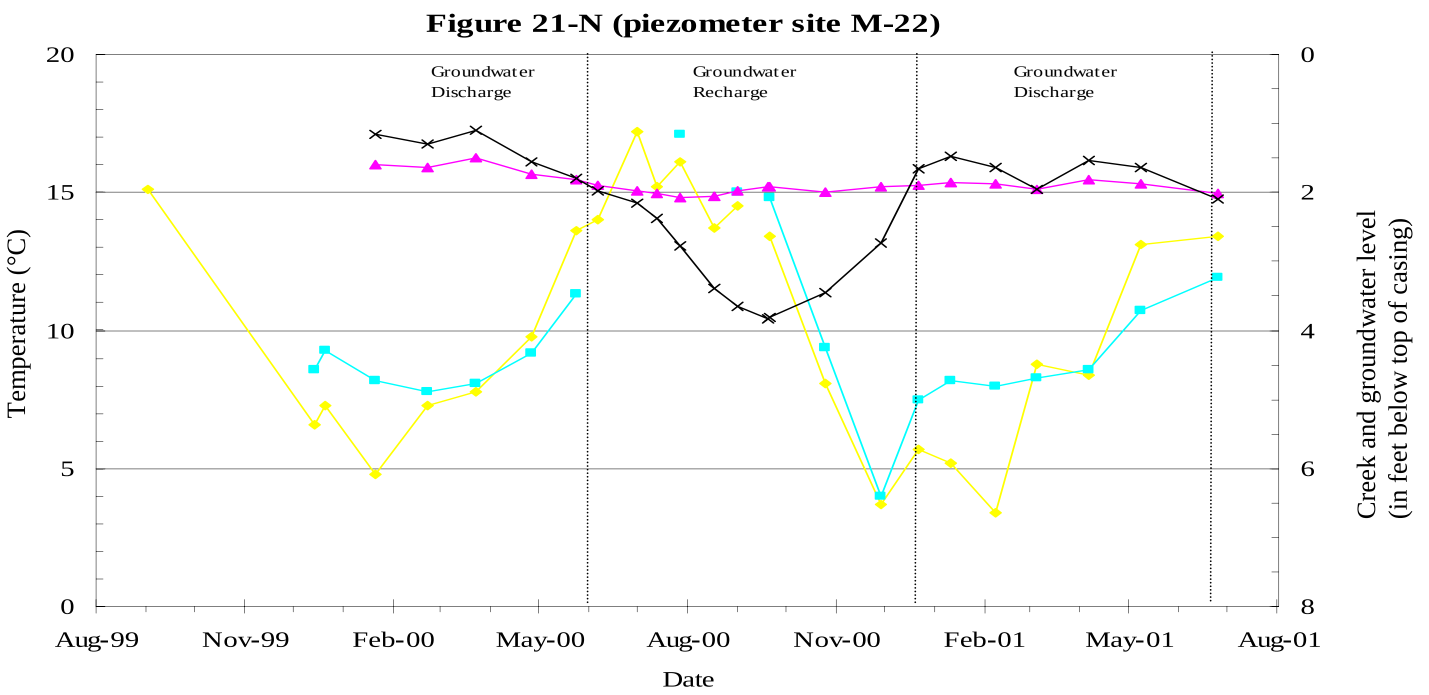


Explanation

Groundwater level — Stream stage — Groundwater temperature — Stream temperature — D - dry

Figure 21 - (Continued) (See Figure 5 for site locations)

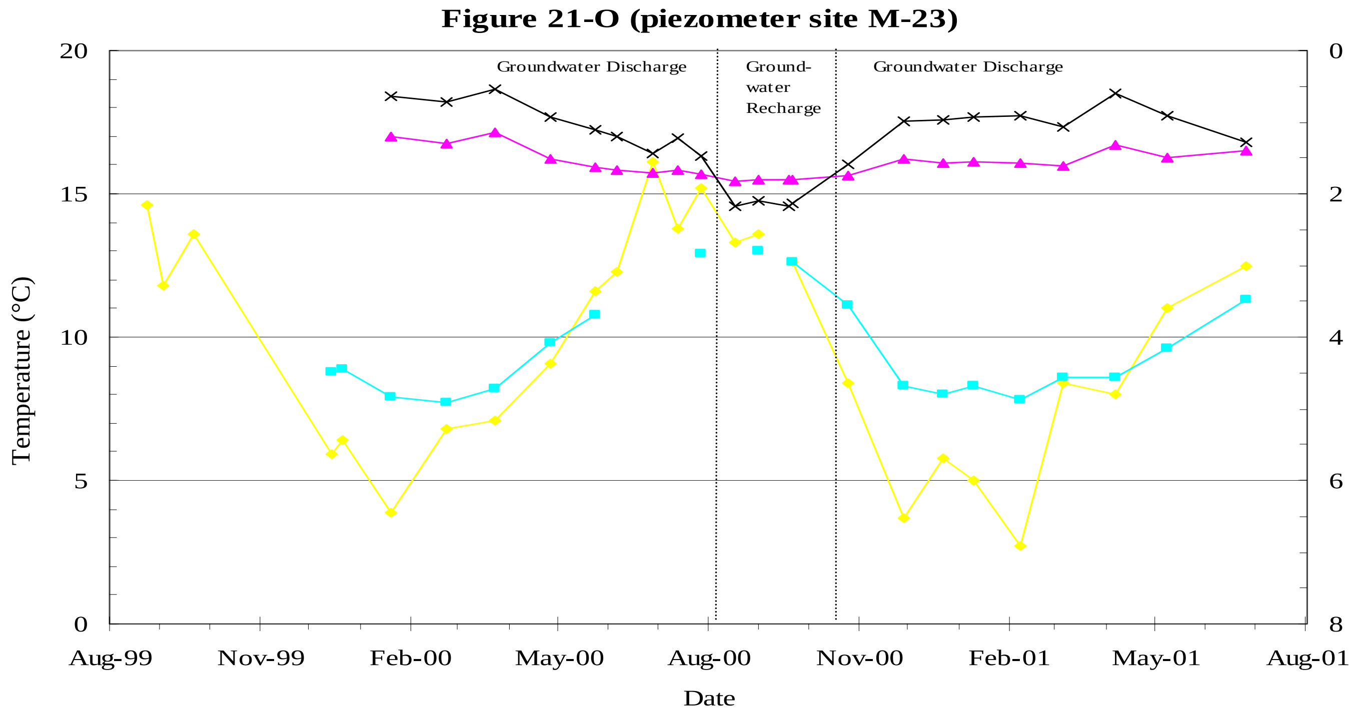


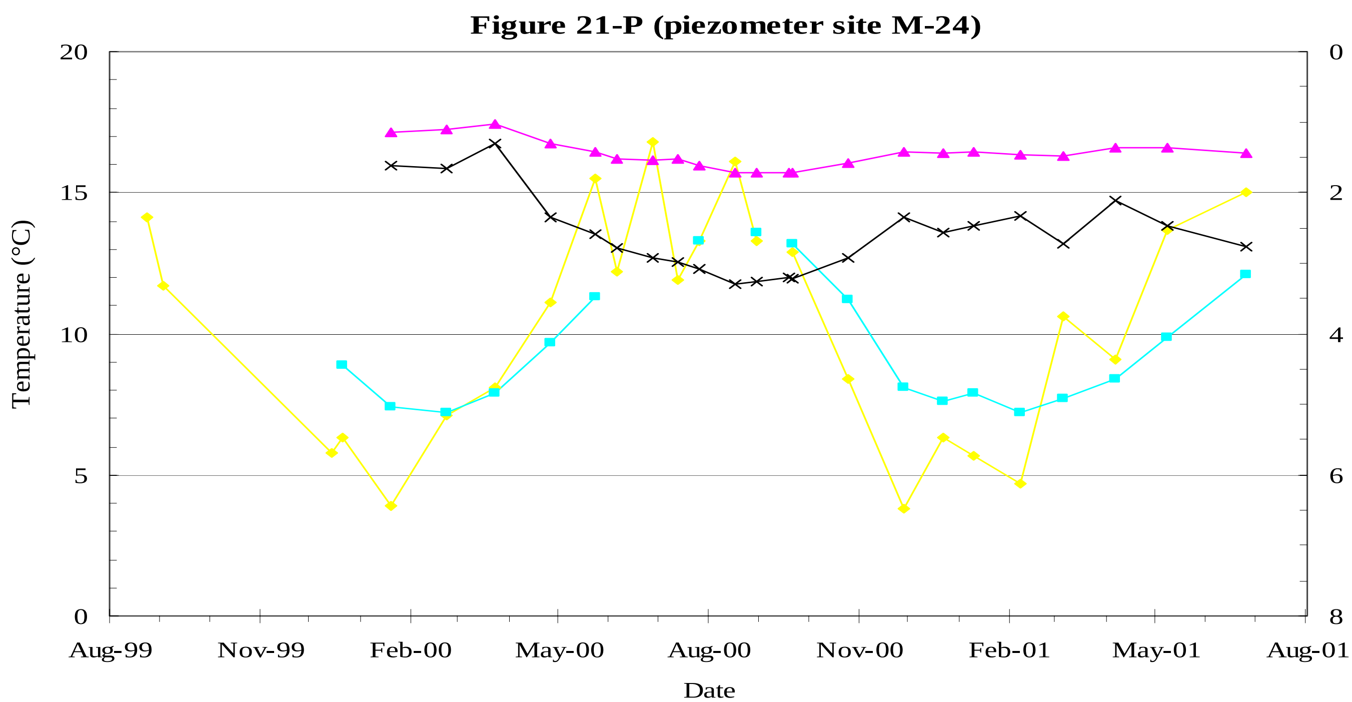


Explanation

Groundwater level — Stream stage — Groundwater temperature — Stream temperature — D - dry

Figure 21 - (Continued) (See Figure 5 for site locations)

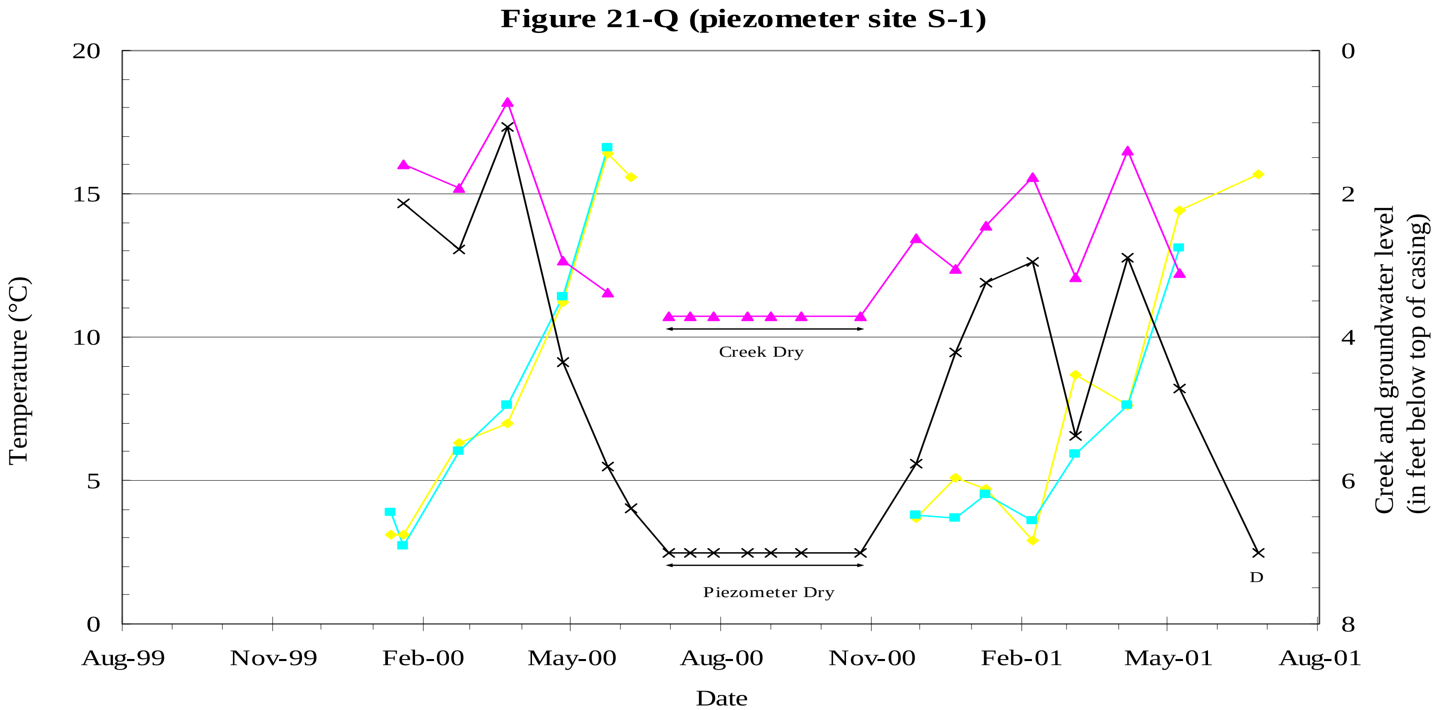


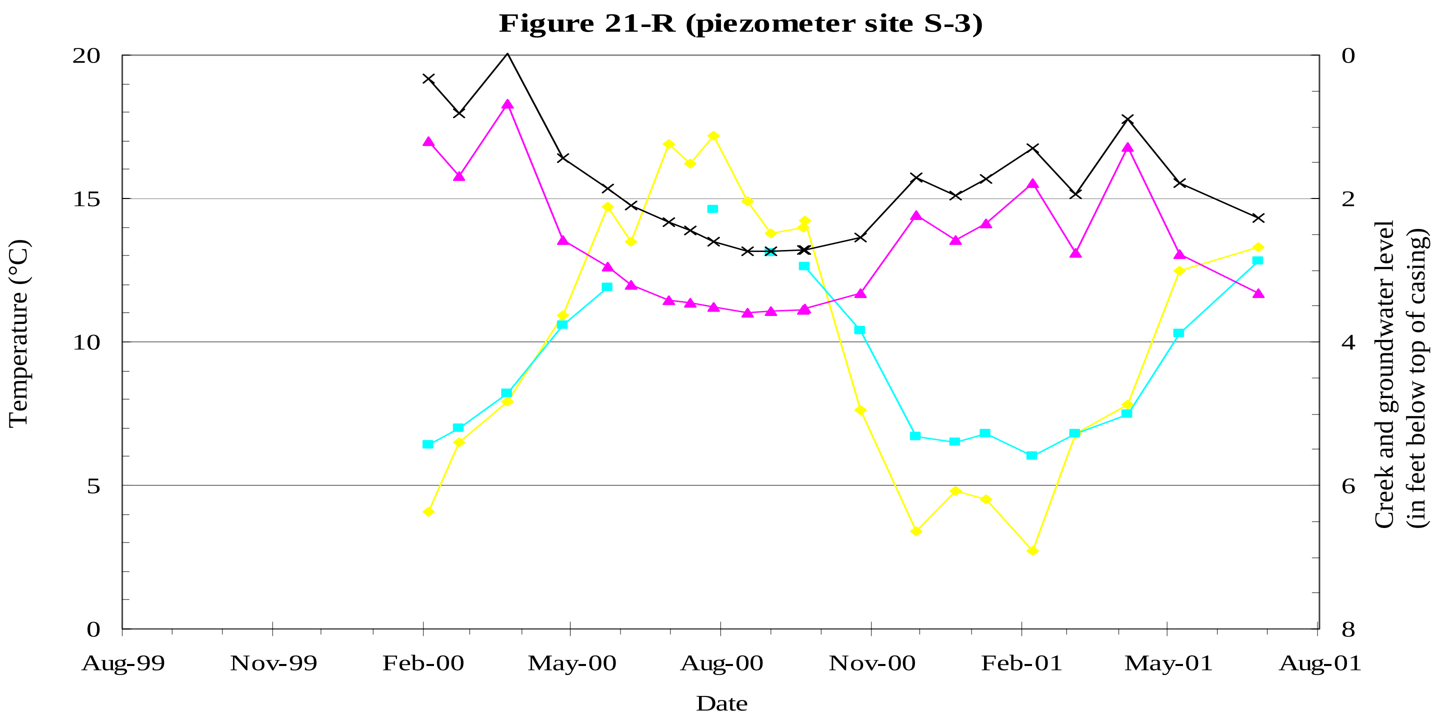


Explanation

Groundwater level   Stream stage   Groundwater temperature   Stream temperature   D - dry

Figure 21 - (Continued) (See Figure 5 for site locations)





Explanation

Groundwater level — Stream stage — Groundwater temperature — Stream temperature — D - dry

Figure 21 - (Continued) (See Figure 5 for site locations)

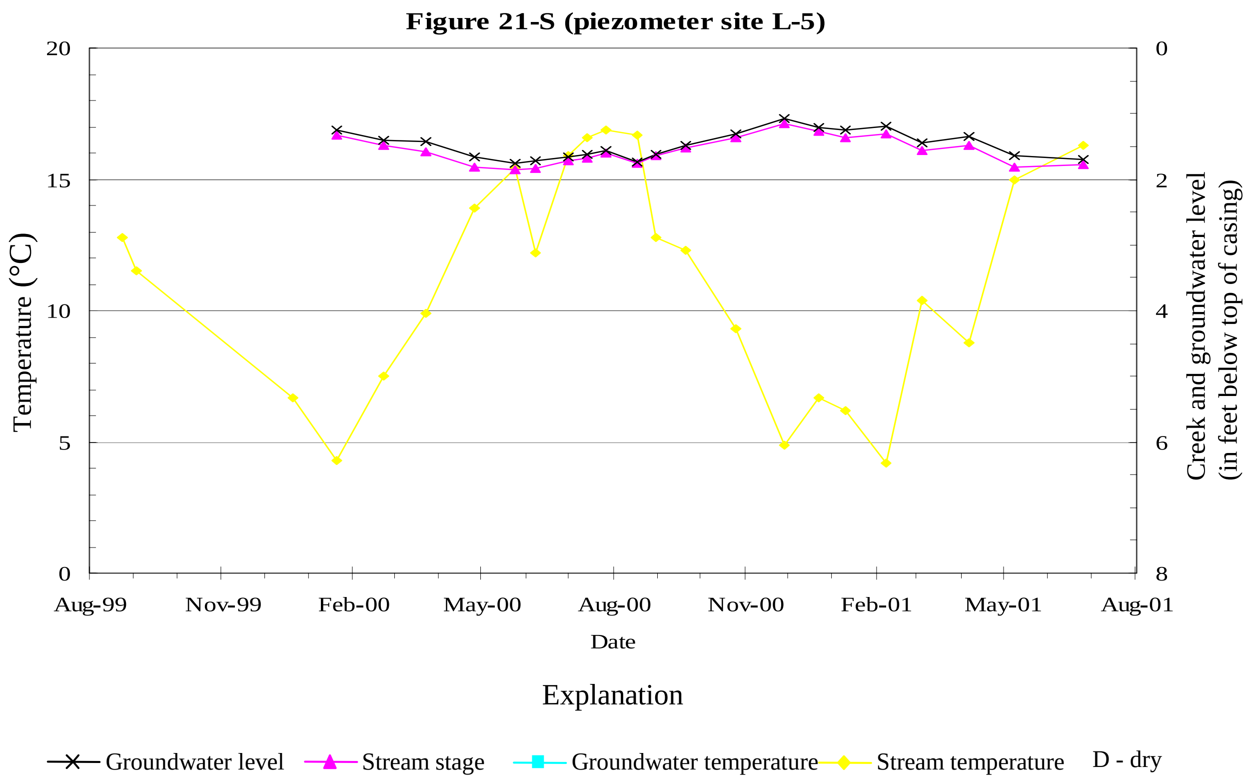


Figure 21 - (Continued) (See Figure 5 for site locations)

The piezometer at site S3 is typical of those located in gaining stream reaches (Figures 5 and 21-R). Groundwater head measurements at site S3 were higher than the stream stage during all monitoring events. The vertical hydraulic gradient between the stream and groundwater was positive and ranged from 0.13 to 0.36. Paired measurements of stream and groundwater temperature were similar during the spring and fall, but diverged by several degrees during the summer and winter when groundwater was generally cooler and warmer than the stream, respectively. Stream temperatures during the monthly monitoring events averaged 9 °C and ranged from 2.7 to17.2 °C, while groundwater averaged 9.3 °C and ranged from 6.0 to 14.6 °C.

The water level and temperature distribution at site M21 is typical of piezometers located in losing streams reaches (Figure 21-M). The stream stage at site M21 exceeded the groundwater head measurements during all sampling events. The vertical hydraulic gradient was negative and ranged from –0.4 to –0.81. Paired measurements of groundwater and stream temperature were within a few degrees in all cases. Stream temperatures during the monthly site visits ranged from 3.0 to 13.2 °C and averaged 7.5 °C, while groundwater temperature ranged from 4.0 to 15.0 °C and averaged 7.7 °C.

The piezometer at site M22 exhibited both gaining and losing stream conditions during the study period (Figure 21-N). Gaining conditions prevailed between December and May when the vertical hydraulic gradient was positive and ranged from 0.01 to 0.19. Groundwater temperatures during this period were usually warmer (in winter) or cooler (in the spring) than the stream by several degrees. Losing conditions prevailed between June and November, when the vertical hydraulic gradient was negative and ranged from –0.02 to –0.48. Stream and groundwater temperatures tracked each other closely during this period (Figure 21-N).

The following sections (1) examine the instream piezometer and seepage results for each of the study area streams, and (2) evaluate how the watershed geology effects the lateral distribution and volume of stream and groundwater interchange.

South Creek

The South Creek drainage encompasses the upland area lying south of the Muck Creek channel and east of Lacamas Creek. Most of the drainage is underlain by Vashon till (Qvt), with lesser deposits of Vashon recessional outwash (Qvr) and recent bog deposits (Figure 7). The recessional outwash is restricted to narrow zones along central and lower South Creek. Upstream of site S6 (Figure 5) the outwash is interspersed with extensive bog deposits and consists mostly of fine grained sand and silt, with lesser amounts of gravel or clay. Below site S6 the outwash consists of coarse gravel and cobbles, with lesser amounts of sand and silt.

An initial reconnaissance by the author in late August 1999, and subsequent observations in 2000, revealed that upper South Creek is mostly dry during the summer and early fall, when it consists of disconnected pools of standing water bisected by long reaches of dry stream bed. Perennial flow was observed between sites S2 and S3, where groundwater discharges to the creek from unit Qvr (Figure 5). Seepage evaluations conducted in June and September 2000 reveal that South Creek gained approximately 0.7 and 0.08 ft3/sec/river mile, respectively, between stations S5 and S3 (Figure 6). Below station S3, South Creek lost water during both evaluations and was dry prior to joining Muck Creek. The greatest loss occurred below station S2 where the stream traverses coarse grained outwash, and lost 4.15 ft3/sec in 2.6 miles, or 1.6 ft3/sec/river mile.

Monitoring data for instream piezometers installed at sites S1 and S3 confirm these gaining and losing relationships. Both the stream and piezometer were dry at site S1 between July and October 2000 (Figure 21-Q). During the remainder of the study, piezometer S1 exhibited negative hydraulic gradients that ranged from –0.11 to –1.03 and averaged –0.44 (Figure 21-Q and Appendix B). The piezometer at site S3, exhibited groundwater discharge conditions throughout the study (Figure 21-R). Vertical hydraulic gradients at site S3 ranged from +0.13 to +0.36 and averaged approximately +0.27.

Together this evidence suggests that South Creek is largely an intermittent stream. It is dry throughout most of its length during the summer and fall, with the exception of a short reach between sites S2 and S3 where the creek receives groundwater discharge from unit Qvr.

Lacamas Creek

Lacamas Creek is underlain by a variety of sediments including Vashon till (Qvt), Vashon recessional outwash (Qvr), and recent bog and peat deposits (Qvr) (Figure 7). The stream above site L4 (Figure 5) is underlain by fine-grained outwash consisting of sand and silt, with lesser amounts of gravel and clay and interspersed till and bog deposits. Below site L4 the stream flows over coarser-grained outwash consisting of cobbles and gravel in a sand and silt matrix.

Lacamas Creek was monitored periodically at five sites (Figure 5) during this investigation and is the only stream that sustained flow throughout its length during the study period. An instream piezometer at site L5, the upper-most monitoring site, exhibited positive hydraulic gradients that ranged from +0.0 to +0.04 and averaged +0.02 (Figure 21-S). Based on the gradient pattern, groundwater discharge to the stream was greatest during the winter and spring (January to mid-June) and lowest during the summer and fall (mid-June through December) (Appendix B). This corresponds with annual fluctuations in area groundwater levels which are generally highest in the spring and lowest in the fall (Figure 17).

The dry season (June through September) streamflow at site L5 averaged approximately 1.0 ft3/sec and ranged from approximately 0.9 to 1.3 ft3/sec (Appendix G). Miscellaneous stream temperature measurements ranged from 4.2 °C in February 2001 to almost 17 °C in July and August 2000 (Appendix B). The stream specific conductance averaged 151 υs/cm during the study period and ranged from 113 υs/cm on January 20, 2000 to 170 υs/cm on August 31, 2000 (Appendix B).

Monitoring site L1, the lowest site on Lacamas Creek (Figure 5), exhibited similar patterns to those observed at site L5. Between June 2000 and June 2001, miscellaneous streamflows at site L1 ranged from approximately 0.37 to almost 11 ft3/sec and averaged approximately 4.8 ft3/sec (Appendix G). Miscellaneous stream temperatures during this period ranged from 1.9 °C in

November 2000 to 17.2 °C in July 2000 and averaged approximately 8.3 °C (Appendix B). The stream specific conductance ranged from 143 to 189 υs/cm and averaged 165 υs/cm and (Appendix B).

Field observations and specific-conductance data suggest that Lacamas Creek provided most of the flow in Muck Creek at site M4 (Roy gage) between June 2000 and December 2000 (Figure 22). The specific conductance of Lacamas Creek is generally higher than Muck Creek during most months, except when Lacamas Creek provided the bulk of the flow in Muck Creek. The streams exhibited very similar specific conductance signatures during this period, suggesting that Lacamas Creek sustained the late summer and fall flows in Muck Creek below their confluence and provided most of the flow in Muck Creek for approximately three months (October 2000 –January 2001) following the onset of winter rains (Figure 22). Flows at site M4 were not dominated by discharge from the Muck Creek drainage until after January 2001 (Figure 22).

Muck Creek

The hydrology of Muck Creek proper is the most diverse of the watershed streams. Muck Creek is perennial in its upper reach but has only intermittent flow through its central reach during most years. The lower reach of the stream contains both perennial and intermittent stream segments. The following discussion examines the mechanisms that control water movement through each of these segments.

Upper Muck Creek (perennial reach)

The upper reach of Muck Creek extends for approximately nine miles from its source at Patterson Springs to just below site M15, at river mile 11.3 (Figure 5). A variety of sediments underlie the stream through this reach, including recent deposits of alluvium and peat as well as Vashon recessional outwash (unit Qvr). The alluvial deposits are generally fine grained and consist mostly of silt and sand with small amounts of clay and gravel. They, along with peat deposits, underlie most of the stream channel between Patterson Springs and site M23 (Figure 5). Advance outwash deposits (unit Qc1) supply Patterson Springs and underlie the stream channel for a short distance below the springs (Figure 7). The remainder of upper Muck Creek (sites M23 to M15) is underlain by unit Qvr consisting of uniformly coarse gravel and cobble and minor amounts of coarse sand (Figure 7).

Ten instream piezometers were installed during this study to evaluate stream and groundwater interchange along upper Muck Creek. Losing conditions were observed throughout the study at eight piezometers (M15-M21 and M24) (Figures 21-G, 21-M, and 21-P), while two sites (M22 and M23) transitioned seasonally between gaining and losing conditions (Figures 21-N and 21-O, respectively). Temperature signatures at the eight losing sites were consistent with the general patterns previously described for site M21. Groundwater and stream temperatures exhibited large seasonal variations at all of the losing piezometers, and tracked each other closely. At sites M22 and M23 groundwater temperatures exhibited smaller annual variations than the stream and generally diverge from the stream temperature during periods of groundwater discharge (Figures 21-N and 21-O).

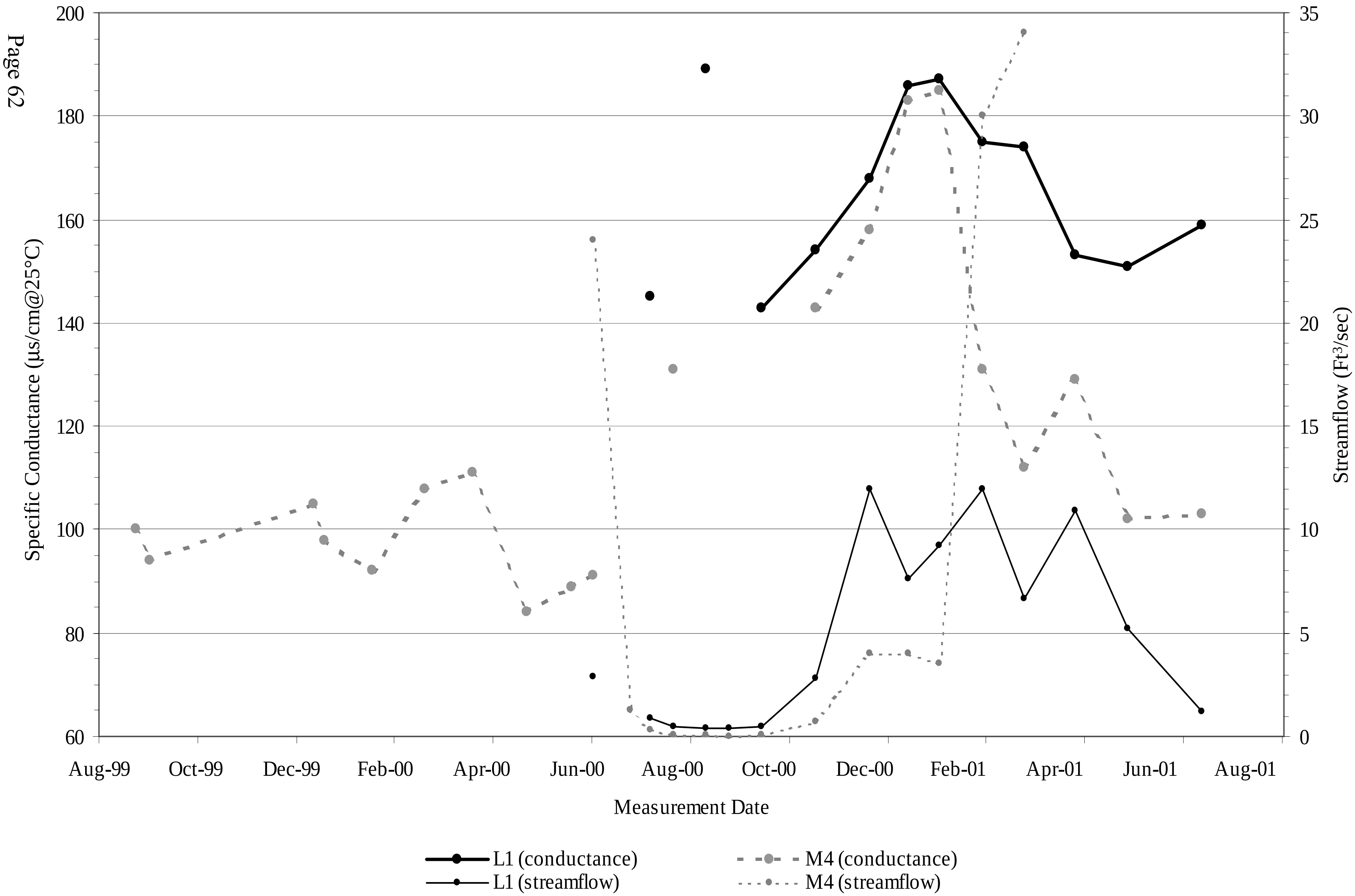


Figure 22 - Comparison of streamflow and specific conductance for Lacamas Creek at site L1 and Muck Creek at site M4

At the lowest sites (M15-M20), the piezometers were dry between June and November, but generally contained water during the remainder of the year (Figures 21-G through 21-L). Lack of water in the piezometers during the summer and fall indicates that the stream is perched above the regional water table, at least seasonally, between sites M15 and M20.

Sites M22 and M23 (Figure 5) are the only piezometers within upper Muck Creek where direct groundwater discharge to the stream occurred. Gaining conditions prevailed at site M22 between December and May and then transitioned to losing conditions between June and November (Figure 21-N). At site M23, gaining conditions prevailed during all months, except for August and September when losing conditions prevailed (Figure 21-O).

These findings are consistent with the patterns observed during stream-seepage evaluations. In June 2000, Muck Creek gained approximately 2.5 ft3/sec between sites M24 and M22 and then lost approximately 0.8 ft3/sec between sites M22 and M18. In September 2000, the stream gained approximately 1.4 ft3/sec between sites M24 and M23 and lost approximately 2.4 ft3/sec between sites M23 and M18 (Figure 6).

Based on the above observations, upper Muck Creek is best characterized as an effluent or losing stream. Most of the dry season flow in this reach originates as tributary springs and seeps that discharge from units Qc1 and Qc2 along the southern margin of the Muck Creek channel (Figure 8, section A). Water from unit Qvr also enters the stream seasonally through its bed at sites M22 and M23 when area groundwater heads temporarily exceed the stream stage. The rate of stream loss is greatest in those segments underlain by recessional outwash, and generally lower in those segments underlain by finer grained alluvium or peat.

Central Muck Creek (intermittent reach)

The central reach of Muck Creek is approximately 2.5 miles in length and extends from just below site M15 (river mile 11.3) to about river mile 8.8 where the stream is joined by a short tributary stream that drains a portion of the lake and wetland complex west of Hwy 507 (Figure 5). This reach is underlain exclusively by Vashon recessional outwash (unit Qvr) consisting of uniformly coarse deposits of cobble and gravel with varying amounts of interstitial sand (Figure 7).

Four instream piezometers were installed along this reach to evaluate surface water and groundwater interchange (sites M11-M14) (Figure 5). Both the stream and piezometers were dry for significant portions of the study period (Figures 21-C through 21-F). However, when the stream contained flow, the piezometers exhibited negative vertical hydraulic gradients, indicating that the stream consistently lost water through this reach. The fact that the piezometers were dry suggests that the stream was perched above the regional water table between sites M11 and M14 during the study period.

During Ecology's February 2001 seepage evaluation, Muck Creek lost 23 ft3/sec between stations M14 and M12 (Figures 5 and 6). Most of this loss occurred between sites M14 and M13 where the stream bed contains abundant cobbles and boulders. While a loss of this magnitude may seem extreme, it is not atypical for this reach. Engle (1997) reported a loss of approximately 53 ft3/sec between sites M18 and M11, during a 1997 seepage evaluation of Muck Creek. Given the drought that prevailed during this study, Engle's findings may be more representative of average conditions than the losses observed during this current Ecology study.

Water that is lost from Muck Creek and South Creek as they traverse the Fort Lewis prairie recharges the local groundwater system and moves generally westward toward the lake and wetland complex west of Highway 507 and points beyond. The general lack of wells north of Roy and west of Highway 507 makes it difficult to say with certainty where the recharge from a particular area or stream ultimately reemerges as groundwater discharge. However, the abundance of wetlands and springs west of Highway 507, within the lower reaches of Muck Creek, and along the eastern seepage face that borders the Nisqually River north of Muck Creek, attests to significant groundwater discharge and, by inference, westward groundwater movement.

Lower Muck Creek (mixed perennial and intermittent reaches)

Lower Muck Creek extends from river mile 8.8 to the mouth of Muck Creek at river mile 0.0 (Figure 5). This segment encompasses the lakes and wetlands to the north and west of Roy and is underlain largely by Vashon recessional outwash (unit Qvr) consisting mostly of cobbles, large gravel, and coarse sand.

The hydrology of lower Muck Creek is influenced by numerous lakes and interconnected wetlands which seasonally store and release runoff from the central and upper reaches of the watershed. Wolcott (1973) identified eight perennial and two intermittent lakes within the lower Muck Creek area. When inventoried, the lakes were described as "shallow" and had a combined surface area of approximately 213 acres. Water levels in at least two of the lakes are artificially regulated via man-made dams. Chambers Lake, northeast of Roy, was dammed at its southern end in1967. It encompasses approximately 80 acres and has a normal storage volume of approximately 320 acre feet. Johnson Lake, which lies to the north of Chambers Lake, was dammed at its southern end in 1976. Johnson Lake has a surface area of approximately 300 acres and a normal storage volume of 300 acre feet.

There is little direct information or data available to evaluate the effect of lakes and reservoirs on the streamflows of lower Muck Creek. Indirect evidence suggests that the lakes and wetlands may significantly alter flows in Muck Creek at least seasonally. Between July and September of 2000, most of the flow in Muck Creek at Roy (site M4) originated from Lacamas Creek which joins Muck Creek approximately 0.5 miles above site M4. This assertion is based on the relative discharge of the two streams and their respective specific conductance signatures. The specific conductance of Lacamas Creek is consistently higher than that of Muck Creek except during the summer and fall (2000) when Lacamas Creek contributed most of the flow measured in Muck Creek at site M4 (Figure 22). Based on their respective specific conductance signatures, discharge from Lacamas Creek continued to dominate streamflows at site M4 from October 2000 through early January 2001 despite the onset of winter rains. The nearly three-month delay in Muck Creek's response to rainfall (relative to that of Lacamas Creek) derives, in part, from geologic differences between the two watersheds, as previously discussed. However, water detention within the lakes and wetlands above site M4 probably accounts for some of the noted delay. Separating the relative influence of these processes was beyond the scope of this investigation.

Instream piezometers were installed at sites M1 and M4 within lower Muck Creek during this study. Losing conditions prevailed throughout the study period at site M1, and the piezometer was dry during all but two measurements (Figure 21-A). This indicates the stream was perched above the regional water table at this location during most (if not all) of the study period. At site M4, the piezometer and stream levels were virtually indistinguishable except between August and October of 2000 when the stream was dry (Figure 21-B). The groundwater level at site M4 closely followed the water level of a shallow dug well near the stream (well AFC086, Figure 17) and indicates that the regional water table seasonally intersects the stream at this site.

Streamflows within the lower 5.5 miles of Muck Creek were evaluated during a 1975-77 water resource evaluation of the Nisqually Lake area by Pearson and Dion (1979). Based on monthly streamflow measurements at sites M1 and M4 and less frequent measurements at site M2, Pearson and Dion concluded that Muck Creek lost water below site M4 between November 1975 and January 1976 (Figure 5 and Appendix G). Between February and December 1976, the stream gained water below site M4. These findings are generally consistent with observations and measurements made during this current study.

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Summary and Conclusions

This study was undertaken to develop a better understanding of the natural interchange that occurs between streams and groundwater within the Muck Creek watershed in Pierce County. The 96-square-mile study area encompasses portions of the broad, grass-covered prairies and coniferous woodlands of eastern Fort Lewis and the surrounding communities of Graham and Roy. The study area was shaped during repeated glaciations over the past few million years and is underlain by as much as 1500 feet of unconsolidated glacial and non-glacial sediments overlying Eocene age bedrock.

The hydrogeologic framework for the study area was described using data from 171 inventoried wells and springs. From this and other information, area sediments were subdivided into nine hydrogeologic units, including five aquifers and four confining units. Groundwater in the study area flows generally toward the west and northwest from upland recharge areas in the eastern watershed toward points of natural groundwater discharge. Groundwater levels were measured monthly in 15 observation wells during the study, and fluctuated from 2 to 16 feet annually. Groundwater levels were generally highest in the spring and lowest in the fall.

Groundwater recharge was estimated using regression equations developed for King County by Woodward et al. (1995) and from stream seepage evaluations conducted during this study. Average annual recharge to the study area was estimated to be approximately 130,000 acre feet, with roughly 17 percent of this total (approximately 22,000 acre feet) being derived from stream leakage. The remainder is derived from direct precipitation on the land surface.

Seasonal intermittent flow is a common condition for central Muck Creek and nearly all of South Creek, particularly during the summer and fall. Streamflow data for Muck Creek at Roy indicate the stream ceased to flow approximately 8.6 percent of the time over the period of record (1956-71, 2000-01). The annual seven-day low flow for Muck Creek at Roy was zero for all but three water years during this period. The upper and central reaches of Muck Creek exhibited effluent or losing stream conditions in most areas during the study period. Most of the dry season flow in upper Muck Creek originates from tributary springs and seeps that discharge from units Qc1 and Qc2 along the southern margin of the Muck Creek channel. The rate of stream loss was greatest in the winter when area streamflows are high. Loss was concentrated along stream segments in central Muck Creek that are underlain by coarse grained deposits of gravel, cobbles, and sand.

Study results indicate that the intermittent flow affecting central Muck Creek and lower South Creek derives largely from natural processes related to the watershed geology. Muck Creek and South Creek are perched above the regional water table within the eastern Fort Lewis prairie, and naturally lose water as they traverse the highly permeable outwash deposits underlying this area. Past human activities, such as stream channel dredging or realignment, may have contributed to additional water loss through this reach. There is no historic data to refute or confirm this possibility.

The perennial reaches of Muck, South, and Lacamas creeks are maintained predominately by groundwater discharge during the summer and fall. Development within the watershed has the potential to impact streamflows by altering natural groundwater recharge and discharge patterns. Continued monitoring of area streamflows, groundwater levels, and spring discharges is recommended to provide a basis for judging the effectiveness of future instream habitat restoration efforts and the effects of future land use changes.

Recommendations

Streams within the Muck Creek watershed are heavily reliant upon natural groundwater discharge to sustain them during the summer and early fall, when precipitation is minimal. Groundwater use and changing recharge patterns due to urbanization have the potential to disrupt or reduce natural groundwater discharge to area streams or their tributary springs.

The following recommendations are provided to help guide area residents and water use managers as they work to enhance or restore instream habitat within the context of these human-caused changes.

1. Establish a permanent groundwater level and spring discharge monitoring program for the watershed.

   The spring discharge values referenced in this report were derived from inventories conducted in the early-to-mid 1960s, and may not accurately depict present spring flows. A subset of the previously monitored springs should be relocated and monitored quarterly for a few years. This will enable water managers to evaluate how area springs have responded to increased groundwater use and urbanization since the last inventory.

   The water-level-observation network established during this study provides a useful baseline for evaluating groundwater level responses to future changes in water use or recharge. Monitoring of the network should be continued on a quarterly or bimonthly basis to provide insight into long-term, water-level trends within the watershed. In rapidly developing areas such as the South Creek upland near Graham, the network should be supplemented with additional wells.

2. Establish permanent gages to monitor area streamflow.

   Continuous streamflow gages provide a convenient and cost-effective means of evaluating a stream's response to short and long-term climatic changes, urbanization, and changing water use patterns. Reliable long-term funding should be secured to operate and maintain the existing Muck Creek gages at Roy (USGS 12090200) and at 8th Avenue East near Loveland. Subject to funding, gages should also be installed at the mouth of Muck Creek and at site S2 (28th Ave E) on South Creek. A gage at site S2 would enable water managers to better quantify the volume of flow that South Creek loses seasonally as it traverses the Fort Lewis prairie complex. A gage at the mouth of Muck Creek would enable water managers to better evaluate streamflow gains and losses between the mouth of Muck Creek and the gage at Roy.

3. Conduct a one-time synoptic measurement of selected area wells during dry season conditions.

   Figure 19 was prepared using water levels from different years and months. Accordingly, it provides only a generalized depiction of groundwater conditions within the study area and is not representative of any single month or year. The ability to evaluate water movement within and between area aquifers is compromised by this lack of specificity. A one-time synoptic measurement of selected area wells should be conducted to provide a detailed assessment of current groundwater conditions.

4. Conduct a detailed evaluation of stream and groundwater interchange within lower Muck Creek.

   This study concentrated on defining stream and groundwater interchange within the central and upper reaches of Muck Creek. Due to Fort Lewis access restrictions, relatively little effort was spent evaluating the lake and wetland complex west of Highway 507, or the lower reach of Muck Creek that traverses the military firing range west of Roy. The hydrology of lower Muck Creek should be evaluated in detail prior to undertaking habitat-enhancement projects within the central and upper watershed. This is particularly important for projects (such as streambed lining) that have the potential to significantly alter groundwater recharge and discharge relationships within the watershed.

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Appendix A

Physical description of inventoried wells and springs in the Muck Creek area

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Appendix A. Physical description of inventoried wells and springs in the Muck Creek area.

EXPLANATION

Well tag number: The Washington State Department of Ecology unique well identification tag number. Identification tags, when present, are typically strapped to the well casing or another permanent fixture of the water system.

Water use: The primary water uses for the well: A, aquaculture; D, domestic supply; F, frost protection; I, irrigation; M, manufacturing; P, public water supply; S, stockwater; T, monitoring or test well; U, unused; -, water use unknown.

Land surface altitude: The land surface altitude, at the well, in feet above mean sea level. All altitudes were determined from 1:24000 USGS topographic maps having 10 or 20 foot contour intervals. The altitudes reported here are generally accurate to within one half of the contour interval or 5 to 10 feet respectively.

Well depth: The completed depth is the maximum depth to which the well can be sounded, in feet below land surface. In some cases the completed depth may be less than the drilled depth reported on the well log.

Casing diameter: The diameter of the well casing, at land surface, in inches.

Completion type and open interval: O, open bottom casing; P, perforated casing; S, well screen with (screen diameter, in inches, if reported); -, completion type unknown. The reported numeric ranges indicate the perforated or screened interval(s), in feet below land surface, through which water enters the well; nr, screened or perforated interval not known.

Well or spring yield: The well yield reported in the drilling report, in gallons per minute; -, no yield reported.

Test method and duration: p, pumped; b, bailed; The reported numeric values indicate the duration, in hours, the well was bailed or pumped in order to determine its yield; 1*, The actual test duration is unknown. One hour was assumed to enable calculation of hydraulic conductivity values.

Drawdown: The difference, in feet, between the pre-test (static) water level and the final pumping water level measured at the completion of the well yield test period; -, drawdown not reported.

Hydrogeologic unit: The hydrogeologic unit(s) that supply water to the well.

Hydraulic conductivity: The horizontal hydraulic conductivity, in units of feet per day, for the hydrogeologic unit taped by the well; -, unable to calculate hydraulic conductivity due to missing data.

Groundwater level: The measured or reported depth to groundwater in the well, in feet below land surface. Steel tape and electric tape measurements are considered accurate to 0.01 and 0.1 feet respectively while reported water levels are considered accurate to the nearest foot.

Water level altitude: The altitude of the well water level, in feet above mean sea level; -, not calculated.

GW level or spring measurement date: The date the groundwater level or spring yield was measured; -, measurement date unknown.

Remarks: D, driller's log available; C, consultant measured water level; E, Ecology measured water level; F, the well is known to flow year round or seasonally; G, USGS measured water level; R, water level reported by driller or owner measurement method unknown; S, water level measured with steel tape; T, water level measured with electric tape; W, well monitored for water level or water quality during this study.

Appendix A- Physical Description of Inventoried Wells and Springs in the Muck Creek Area

Local Number	Well Tag Number	Site Latitude (dms)	Site Longitude (dms)	Water use	Land surface altitude (feet)	well depth (feet)	Casing diameter (inches)	Completion type and open interval (feet)	Well or Spring yield (gpm)	Drawdown Test method and duration (hours)	Draw-down (feet)	Hydrogeologic unit	Horizontal Hydraulic conductivity (feet per day)	Groundwater level, below land surface (feet)	Groundwater level altitude (feet)	GW level or spring measurement date	Remarks
17N/02E-01K02		465911	1222927	DIS	395	183	10	P 116-176	348	4	39		39.5	60	335	-	DR
17N/02E-01N02		465858	1222957	DS	400	113	6	O	8	1*	4		123	93	307	05/1954	DR
17N/02E-02E01		465925	1223124	AD	380	139	6	O	50	1	21	Qc4	146	52	328	11/26/1980	DR
17N/02E-02M01		465915	1223123	P	405	138	8	O	210	4.5	15		644	82.3	323	08/29/1985	DR
17N/02E-02P01		465902	1223111	P	380	99	6	O	96	1	27		218	60	320	10/02/1979	DR
17N/02E-03E01		465942	1223232	DI	335	128	8	S 85-128	45	1	38		5.85	11	324	04/23/1981	DR
17N/02E-03L01		465907	1223156	D	425	200	6	O	20	1	21		58	115	310	10/26/1979	DR
17N/02E-11A01		465847	1223019	P	410	138	6	O	15	1*	-		-	8	402	02/15/1991	DR
17N/02E-11J01		465816	1223031	P	420	201	8	S 193-198	124	4	78		76.4	98	322	09/17/1984	DR
17N/02E-24H01		465653	1222902	-	440	24	60	O	-	-	-		-	12	428	-	DR
17N/02E-38B01		465936	1223242	P	330	496	12	S(10in) 444-469,478-488	496	p 24	21.7		212	58	272	12/16/1985	DR
17N/03E-01E01		465917	1222226	P	570	165	6	O	25	-	-		-	63	507	09/14/1987	DR
17N/03E-01R01	AFC088	465852	1222131	D	615	220	6	O	60	1*	-		-	63.3	552	07/26/2000	DTW
17N/03E-01R02		465852	1222128	P	615	140	6	O	50	p 6	27		7	72	543	05/03/1979	DR
17N/03E-02B01		465934	1222315	P	560	98	6	O	75	p 4	16.7		275	58	502	04/16/1988	DR
17N/03E-03K01		465911	1222418	I	595	207	10	P 120-127, 139-193	250	4	16.5		57.1	55.6	539	07/08/1980	DR
17N/03E-04A01		465932	1222515	P	510	209	8	S 204-209	40	b 1	30	Qc4	57.2	60	450	11/01/1962	DR
17N/03E-04F01		465925	1222604	P	510	177	6	O	40	b 1	25	Qc4	98	131	379	09/14/1987	DR
17N/03E-05E01		465927	1222740	-	420	70	6	O	29	4	10	Qc4	178	48	372	05/20/1948	DR
17N/03E-05G01		465927	1222704	IP	435	139	10	S 134-139	234	p 3.5	6.3	Qc4	2190	50	385	08/19/1974	DR
17N/03E-05N01		465901	1222743	P	435	154	6	O	26	4	52		31	60	375	12/15/1987	DR
17N/03E-06Q01		465852	1222817	-	395	252	8	P 60-65, 96-108	-	-	-		-	35	360	1952	DR
17N/03E-07B01		465848	1222808	P	420	120	6	O	-	-	-		-	55	365	06/16/1987	DR
17N/03E-07N01S		465812	1222840	-	400	-	-	-	-	-	-		-	-	-	-	-
17N/03E-08F01		465831	1222722	DI	420	247	8	O	30	b 1*	15		23	30	390	07/10/1966	DR
17N/03E-08M01		465822	1222731	I	412	108	6	O	30	1	66		28	18	394	11/17/1981	DR
17N/03E-08R01		465809	1222648	DI	435	99	8	S 91-99	100	1	45	Qc3	62	0.33	435	07/21/1960	DGR
17N/03E-09D01		465848	1222620	P	485	203	6	O	50	p 4	33	Qc4	93	70	415	01/08/1985	DR
17N/03E-10A01		465845	1222400	-	600	87	6	-	-	-	-		-	85.1	515	02/09/1954	DGR
17N/03E-13E01		465739	1222238	ADI	570	131	8	P 122-130	30	2	21		40.5	89	481	06/07/1972	DR
17N/03E-16D01		465756	1222624	P	485	140	6	P(4.5) 98-126	37.5	1*	nr	Qc3	-	51	434	07/27/1990	DR
17N/03E-16D02		465753	1222625	D	485	138	8	S nr	60	p 4	100	Qc3	-	35	450	09/12/1978	DR
17N/03E-16D03	AFC089	465753	1222625	U	485	110	6	P 70-105	15	b 1	80		1.03	35.46	450	06/28/2000	DTW
17N/03E-16E02		465742	1222624	D	480	86	6	O	20	1*	1	Qc3	1226	42	438	-	DR
17N/03E-17F01		465745	1222710	-	445	14	36	-	-	-	-		-	5.71	439	10/14/1959	DGS
17N/03E-17G01		465740	1222700	-	465	75	42	-	-	-	-		-	39	426	01/01/1930	DR
17N/03E-17N01		465713	1222739	P	445	56	6	S 48-53	40	1	7		283	19	426	04/23/1989	DR
17N/03E-20A01		465705	1222633	D	490	67	6	O	20	1*	-	Qc3	-	0	490	-	DFR
17N/03E-21D02		465702	1222624	DS	480	66	10	O	110	1*	10	Qc3	405	-	-	-	D
17N/03E-21M01		465636	1222625	D	480	80	6	O	30	1*	56	Qc3	33	1.51	478	08/11/1960	DFGR

Appendix A- Physical Description of Inventoried Wells and Springs in the Muck Creek Area

Local Number	Well Tag Number	Site Latitude (dms)	Site Longitude (dms)	Water use	Land surface altitude (feet)	well depth (feet)	Casing diameter (inches)	Completion type and open interval (feet)	Well or Spring yield (gpm)	Drawdown Test method and duration (hours)	Draw-down (feet)	Hydrogeologic unit	Horizontal Hydraulic conductivity (feet per day)	Groundwater level, below land surface (feet)	Groundwater level altitude (feet)	GW level or spring measurement date	Remarks
17N/03E-24E01		465643	1222229	P	550	79	6	O	40	b 1	14		175	40	510	03/26/1990	DR
17N/03E-24M01		465636	1222236	P	542	79	6	O	40	b 1	5		490	38	504	06/06/1990	DR
17N/03E-26L01		465546	1222327	P	570	140	6	O	41	p 4	30		84	84	486	11/12/1981	DR
17N/03E-28L01		465537	1222553	P	480	113	6	O	100	p 4	30		204	6	474	11/20/1985	DR
17N/03E-37D01		465945	1222851	P	400	166	10	O	186	-	-	Qc4	-	49	351	08/05/1970	DR
17N/04E-01J01		465904	1221408	P	700	78	6	O	10	b 1	15		41	55	645	04/15/1986	DR
17N/04E-01N01		465902	1221511	-	683	52	6	-	20	-	15		-	9.22	674	09/12/1960	DGS
17N/04E-02M01	AFC096	465912	1221623	I	650	175	6	O	30	1*	-		-	8.87	641	06/28/2000	DFTW
17N/04E-02M02	AFC097	465912	1221625	I	650	79	6	O	30	1*	45		41	8.1	642	11/29/2000	DTW
17N/04E-04L01		465910	1221825	P	640	220	6	O	60	p 4	15	Qc3	192	43	597	11/03/1988	DR
17N/04E-04P01		465852	1221839	P	655	135	6	O	80	p 4	43	Qc2	114	-	-	-	D
17N/04E-04P02		465901	1221839	P	640	139	6	O	30	b 1	4	Qc2	460	37	603	12/02/1986	DR
17N/04E-04Q01		465858	1221808	-	640	97	6	-	10	-	10		-	31	609	06/01/1953	DR
17N/04E-05A01		465940	1221908	DIS	615	135	6	O	100	4	25	Qc1	245	10	605	07/02/1951	DR
17N/04E-05C01		465942	1221952	DI	730	68	6	S 63-68	20	4	25		38.1	23	707	03/15/1976	DR
17N/04E-05Q01		465851	1221926	DI	625	72	6	O	28	p 8	20		86	16	609	10/07/1960	DR
17N/04E-07C01	AFC085	465847	1222100	DI	630	98	6	O	20	1	20		61	36.71	593	07/26/2000	DTW
17N/04E-08B01		465848	1221926	D	615	79	8	O	30	b 1	45		31	13	602	03/31/1987	DR
17N/04E-10B01		465846	1221704	DI	640	124	8	P 59-70, 105-123	54	b 5	52		8.2	3	637	09/24/1965	DR
17N/04E-10E01		465835	1221730	T	643.5	78	2	S 68-78	-	-	-		-	10.26	633	07/08/1989	CDR
17N/04E-10M02		465819	1221747	T	654.8	201	2	S 195.5-201	-	-	-		-	5.76	649	07/08/1989	CDR
17N/04E-10F01		465825	1221713	T	651	77	2	S 67-77	-	-	-		-	8.26	643	07/08/1989	CDR
17N/04E-10C01		465846	1221713	T	631.2	58	2	S 48-58	-	-	-		-	5.49	626	07/08/1989	CDR
17N/04E-10M01		465820	1221747	T	654.6	56.4	2	S 46.4-56.4	-	-	-		-	18.57	636	07/08/1989	CDR
17N/04E-10L01		465816	1221714	T	659.3	70.5	2	S 60.5-70.5	-	-	-		-	6.1	653	07/08/1989	CDR
17N/04E-15C01		465755	1221715	T	719.7	78	2	S 68-78	-	-	-		-	37.21	682	07/08/1989	CDR
17N/04E-10N01		465802	1221746	T	662.5	100.5	2	S 90.5-100.5	-	-	-		-	12.92	650	07/08/1989	CDR
17N/04E-12N01S		465809	1221500	-	650	-	-	-	-	-	-		-	-	-	-	-
17N/04E-16C01		465751	1221828	P	640	77	6	P 65-77	37	p 4	61	Qc1	12.5	10.5	630	09/04/1987	DR
17N/04E-16H01		465737	1221754	I	750	149	10	S(8 in) 139-149	100	1	40	Qc1	56.3	80	670	07/19/1979	DR
17N/04E-20A01		465654	1221913	DI	695	64	6	O	10	b 1	35		18	20	675	10/27/1975	DR
17N/04E-20R01S		465612	1221909	-	666	-	-	-	-	-	-		-	-	-	-	-
17N/04E-22K01		465632	1221701	D	625	125	6	O	-	-	-		-	-	-	-	D
17N/04E-29M01		465541	1222002	D	655	203	6	S 198-203	20	b 1*	29		29.4	63	592	06/28/1968	DR
17N/04E-29N01		465528	1222011	DS	625	185	6	O	40	b	-		-	-	-	-	D
18N/01E-36P01S		465950	1223727	-	240	-	-	-	-	-	-		-	-	-	-	-
18N/02E-08H01	AEP008	470352	1223405	T	318.1	43	2	S 38-43	-	-	-		-	27.5	291	07/01/1999	CDR
18N/02E-11L01	AEP012	470337	1223112	T	349	39	2	S 34-39	-	-	-		-	21.1	328	07/01/1999	CDR
18N/02E-16G01	AEP009	470257	1223310	T	326.6	49	2	S 44-49	-	-	-	Qvr	-	26	301	07/01/1999	CDR
18N/02E-19N01	AEP011	470133	1223629	T	280.3	46	2	S 41-46	-	-	-		-	27	253	07/01/1999	CDR

Appendix A- Physical Description of Inventoried Wells and Springs in the Muck Creek Area

Local Number	Well Tag Number	Site Latitude (dms)	Site Longitude (dms)	Water use	Land surface altitude (feet)	well depth (feet)	Casing diameter (inches)	Completion type and open interval (feet)	Well or Spring yield (gpm)	Drawdown Test method and duration (hours)	Draw-down (feet)	Hydrogeologic unit	Horizontal Hydraulic conductivity (feet per day)	Groundwater level, below land surface (feet)	Groundwater level altitude (feet)	GW level or spring measurement date	Remarks
18N/02E-21L01	AEP006	470145	1223334	T	316	44	2	S 39-44	-	-	-	Qvr	-	29.4	287	07/01/1999	CDR
18N/02E-33J01		470008	1223300	DFI	310	55	10	S 39.5-55	500	p 4	1.5	Qc3	29300	6.5	304	12/20/1975	DR
18N/02E-33J02		470009	1223256	P	310	154	12	S(10 in) 80-90, 95-100	625	p 9.4	3.14	Qc3	11100	8	302	12/30/1985	DR
18N/02E-33K01	AFC087	470003	1223323	P	315	140	6	O	30	1*	-	Qc4	-	91.4	224	06/28/2000	DETW
18N/02E-34G02		470018	1223156	P	335	145	6	O	30	p 4	107	Qc4	17	12	323	11/18/1977	DR
18N/02E-34G01		470023	1223200	I	325	26	8	P 14-26	150	4	2.5	Qvr	977	12.07	313	05/08/1951	DGR
18N/02E-34J01		470010	1223137	D	335	120	6	O	40	b 1	1	Qc4	2452	45	290	09/23/1983	DR
18N/02E-34N01	AFC086	465958	1223241	I	319	15	36	O	-	-	-		-	7.9	311	07/26/2000	ETW
18N/02E-34R01		465959	1223134	P	355	107	6	O	15	-	86		11	38	317	07/15/1976	DR
18N/03E-07N01S		470324	1222842	-	370	-	-	-	100	-	-		-	-	-	-	-
18N/03E-12G01		470348	1222148	I	445	284	10	S(8 in) 270-284	350	p 24	144		48.2	45	400	02/05/1990	DR
18N/03E-12M01		470335	1222230	P	440	447	16	S(12 in) 404-445	1500	p 0.66	145.5		62.4	75.8	364	08/24/1979	DR
18N/03E-13K01		470243	1222145	P	492	78	6	S 73-78	20	b 1	15		59.7	45	447	10/06/1978	DR
18N/03E-14A01		470308	1222249	D	425	57	6	O	8	1*	5		98	27	398	04/01/1953	DR
18N/03E-14K01		470236	1222302	P	440	181	8	P 160-180	40	b 1	50		8.2	29	411	06/18/1975	DR
18N/03E-24B01		470214	1222158	P	482	79	6	O	70	b 1	42	Qc3	102	18	464	05/24/1978	DR
18N/03E-24N01		470133	1222225	P	472	120	6	O	25	1	50	Qc3	31	28	444	04/20/1984	DR
18N/03E-24N01S		470130	1222220	-	470	-	-	-	-	-	-	Qvr	-	-	-	-	-
18N/03E-25M01		470103	1222228	P	450	92	6	O	60	4	11	Qc3	334	19	431	12/28/1989	DR
18N/03E-25P01	AFC092	470056	1222207	I	455	83	6	S 78-83	50	p 5	10	Qc3	272	23.72	431	07/26/2000	DETW
18N/03E-44N01S		470038	1222203	-	450	-	-	-	-	-	-	Qvr	-	-	-	-	-
18N/03E-26N01		470100	1222353	D	435	78	6	O	40	b 1	18		136	22	413	08/07/1992	DR
18N/03E-26P01	AFC090	470100	1222319	D	445	89	6	O	30	1	45		41	37.03	408	07/26/2000	DETW
18N/03E-34D01		470011	1222511	DI	450	118	6	O	40	4	40		61	40	410	04/13/1976	DR
18N/03E-34E01		470003	1222500	P	445	164	8	S 153-164	118	b 4	32	Qc4	85.3	43	402	06/24/1985	DR
18N/03E-34J01	ABD831	470001	1222409	D	462	110	6	O	38	3	0	Qc3	2330	46.75	415	07/26/2000	DETW
18N/03E-35F01		470010	1222330	D	460	106	6	O	10	b 2	15	Qc3	41	40	420	09/10/1999	DR
18N/03E-35G01	AFC091	470011	1222318	D	448	56	6	O	10	1*	-	Qc3	-	15.42	433	07/26/2000	DETW
18N/03E-35G01S		470011	1222316	-	450	-	-	-	-	-	-	Qvr	-	-	-	-	-
18N/03E-36E01S		470020	1222239	-	465	-	-	-	20	-	-	Qvr	-	-	-	-	-
18N/03E-36F01		470014	1222210	P	495	100	8	S 95-100	120	4	31	Qc3	209	55	440	04/01/1983	DR
18N/03E-36H01		470017	1222127	P	670	177	8	S 173-177	20	b 4	12	Qc2	80.3	140	530	02/25/1982	DR
18N/04E-01N01		470412	1221454	P	585	145	8	S 140-145	75	1*	-		-	70	515	01/31/1991	DR
18N/04E-01Q01S		470406	1221413	-	600	-	-	-	-	-	-		-	-	-	-	-
18N/04E-02E01		470431	1221603	P	582	210	6	O	30	b 1	40		46	146	436	09/24/1982	DR
18N/04E-02H01		470439	1221502	P	560	150	6	O	50	b 4	22.6		133	108	452	12/28/1987	DR
18N/04E-02H02	AES933	470436	1221506	D	570	195	6	S 155-195	10	1*	-		-	119	451	07/08/1999	DR
18N/04E-04A01	AFC051	470451	1221751	P	540	188	8	S 178-188	55	p 5	55		23.6	101.5	438	05/31/2000	DET
18N/04E-05R01		470414	1221901	P	462	95	6	O	50	p 4	44		70	26	436	12/04/1989	DR
18N/04E-06P01		470406	1222102	P	475	188	8	O	35	b 1*	80		20	80	395	07/02/1971	DR

Appendix A- Physical Description of Inventoried Wells and Springs in the Muck Creek Area

Local Number	Well Tag Number	Site Latitude (dms)	Site Longitude (dms)	Water use	Land surface altitude (feet)	well depth (feet)	Casing diameter (inches)	Completion type and open interval (feet)	Well or Spring yield (gpm)	Drawdown Test method and duration (hours)	Draw-down (feet)	Hydrogeologic unit	Horizontal Hydraulic conductivity (feet per day)	Groundwater level, below land surface (feet)	Groundwater level altitude (feet)	GW level or spring measurement date	Remarks
18N/04E-06R01		470415	1222022	P	445	110	8	S 91-96, 100-110	150	b 1	68		32.8	43	402	10/01/1990	DR
18N/04E-05R02		470405	1221856	P	430	101	8	O	20	b 1	2		460	19	411	08/02/1983	DR
18N/04E-08A01		470400	1221901	P	430	80	8	O	45	b 1	1	Qc3	2069	14	416	06/28/1985	DR
18N/04E-08G02		470341	1221920	-	495	145	6		-	-	-		-	-	-	-	D
18N/04E-08H01		470347	1221856	M	512	272	10	S(8 in) 220-230, 249-252, 263-268	90	4	57	Qc4	7.9	100	412	08/09/1973	DR
18N/04E-08K01		470339	1221930	T	520	130	2	S 120-130	-	-	-		-	105	415	01/14/1999	DR
18N/04E-09A01		470359	1221740	-	575	111	42	-	-		-		-	74.4	501	06/06/1960	DGS
18N/04E-09L01	ABS477	470331	1221823	T	550	76	2	S 71-76	-	-	-		-	70.98	479	08/12/1997	DGS
18N/04E-09Q01		470316	1221810	-	545	130	6	P 97-118	20	-	-		-	77.9	467	06/03/1960	DGS
18N/04E-09R01		470317	1221745	-	590	73	42	-	-	-	-		-	6.47	584	07/17/1958	DGS
18N/04E-10A01S		470357	1221630	-	590	-	-	-	-	-	-		-	-	-	-	-
18N/04E-10M01		470334	1221727	P	550	240	8	P 200-240	50	p 7	126		2.25	66	484	05/08/1981	DR
18N/04E-11A01		470359	1221520	P	625	177	8	O	100	p 4	56		82	84	541	10/09/1983	DR
18N/04E-11A02	ABR903	470354	1221508	P	630	59	6	O	40	4	20		123	18	612	03/25/1982	DR
18N/04E-11P01		470313	1221550	P	760	99	6	O	62	p 4	2.5		1520	74	686	02/17/1988	DR
18N/04E-12B01S		470358	1221418	-	645	-	-	-	5	-	-		-	-	-	-	-
18N/04E-13A01		470258	1221349	P	830	208	6	O	30	b 1	15		123	170	660	01/19/1983	DR
18N/04E-13F01		470256	1221439	P	760	138	6	S 133-138	66	p 4	31		108	75	685	05/10/1989	DR
18N/04E-14A01		470309	1221514	P	750	105	6	O	15	1	1		920	70	680	11/10/1979	DR
18N/04E-14B01		470305	1221532	I	768	115	8	P 100-115	100	1*	20		78.9	79.91	688	06/06/1960	DGS
18N/04E-14C01	AFC094	470308	1221546	U	780	65	4	O	8	4	1		736	53.58	726	07/26/2000	ETW
18N/04E-15A01S		470302	1221633	-	681	-	-	-	-	-	-		-	-	-	-	-
18N/04E-15E02		470250	1221736	-	630	106	6	-	6		20		-	33.4	597	06/03/1960	DGS
18N/04E-15H01		470250	1221622	P	860	300	8	S 278-298	256	p 4	2		2400	232	628	08/10/1981	DR
18N/04E-15K01S		470245	1221703	-	700	-	-	-	-	-	-		-	-	-	-	-
18N/04E-15N02		470227	1221732	DS	760	101	6	O	-	-	-		-	88	672	06/13/1960	DGS
18N/04E-15P01		470225	1221712	D	790	216?	6	O	12	1*	1		736	155	635	08/06/1952	DR
18N/04E-16D01		470309	1221841	P	525	177	8	O	30	4	6	Qc4	230	43	482	04/24/1977	DR
18N/04E-16E01		470247	1221841	D	515	98?	6	O	-	-	-	Qc3	-	32.65	482	06/02/1960	DGS
18N/04E-16F01		470254	1221828	P	550	90	6	O	28	b 1.5	15		114	40	510	03/12/1975	DR
18N/04E-16P01S		470221	1221816	-	665	-	-	-	-	-	-		-	-	-	-	-
18N/04E-17N01		470233	1222006	P	515	120	6	O	30	b 1	50		37	39	476	02/02/1981	DR
18N/04E-18J01	ABS478	470234	1222020	T	505	37	2	S 32-37	-	-	-		-	18.03	487	07/30/1997	DGS
18N/04E-18P01		470227	1222052	P	490	75	6	O	40	b 1	12		204	19	471	06/29/1978	DR
18N/04E-18R01		470224	1222022	P	512	103	8	P 52-98	60	5	10		34.7	70	442	02/17/1976	DR
18N/04E-19Q01	ABS484	470131	1222040	T	510	42	2	S 37-42	-	-	-		-	29.75	480	11/29/1996	DGS
18N/04E-20A01		470219	1221901	P	500	66	6	O	100	p 4	17	Qc4	361	12	488	06/16/1988	DR
18N/04E-20L01		470150	1221938	P	482	39	6	O	40	p 4	8		307	10	472	11/21/1984	DR
18N/04E-20N01		470137	1222009	P	498	93	6	O	20	b 1	30		41	32	466	04/15/1978	DR
18N/04E-21A01		470208	1221742	P	845	240	6	O	18	p 3	20		55	200	645	08/28/1972	DR

Appendix A- Physical Description of Inventoried Wells and Springs in the Muck Creek Area

Local Number	Well Tag Number	Site Latitude (dms)	Site Longitude (dms)	Water use	Land surface altitude (feet)	well depth (feet)	Casing diameter (inches)	Completion type and open interval (feet)	Well or Spring yield (gpm)	Drawdown Test method and duration (hours)	Draw-down (feet)	Hydrogeologic unit	Horizontal Hydraulic conductivity (feet per day)	Groundwater level, below land surface (feet)	Groundwater level altitude (feet)	GW level or spring measurement date	Remarks
18N/04E-21E02S		470157	1221852	-	640	-	-	-	500	-	-		-	-	-	-	-
18N/04E-21J01		470148	1221753	P	950	408	12	S(10 in) 380-398	275	p 24	19.4		239	310.7	639	03/06/1997	CDR
18N/04E-22E01		470202	1221730	P	895	327	8	S 317-327	200	p 5	4.5		1390	241.3	654	12/02/1980	CDR
18N/04E-23C01		470208	1221600	-	750	81	6	-	15	-	1		-	43.4	707	06/07/1960	DGS
18N/04E-25E01		470101	1221457	-	715	25	48	O	-	-	-		-	10.9	704	06/15/1960	DGS
18N/04E-25Q01		470034	1221417	P	700	140	6	P nr	10	b 1	20	Qc1	-	70	630	04/25/1983	DR
18N/04E-28D01		470125	1221845	P	755	218	6	O	36	1	3	Qc2	736	124	631	10/10/1978	DR
18N/04E-28J01		470049	1221745	-	720	80	6	-	-	-	-		-	2.88	717	06/15/1960	DGR
18N/04E-28M01		470057	1221848	P	698	114	6	O	60	1*	-	Qc2	-	40	658	08/05/1986	DR
18N/04E-29E01	AFC093	470108	1222013	D	471	60	6	O	20	b 1	26		47	4.61	466	07/26/2000	DESW
18N/04E-30A02		470120	1222017	-	485	77	8	-	25	-	15		-	42	443	09/03/1952	DR
18N/04E-30D01		470126	1222117	P	488	104	6	P 85-100	30	p 4	56		8.3	36	452	11/18/1980	DR
18N/04E-30H01	AFC098	470109	1222018	D	472	No Log	6	-	-	-	-		-	10.76	461	07/26/2000	ETW
18N/04E-31J01		470008	1222022	P	712	216	6	S 205-216	120	4	5	Qc2	650	115	597	02/20/1985	DR
18N/04E-31J02	AEF412	465959	1222026	P	705	62	6	S 50-60	13.6	4	24		13.2	30	675	04/23/1985	DR
18N/04E-32A01		470032	1221909	-	750	167	8	P 162-167	100	1*	58	Qc1	75.5	82	668	-	DR
18N/04E-32C01	AEF394	470030	1221949	P	725	80	6	O	100	p 4	29.5	Qc1	208	26	699	06/14/1984	DR
18N/04E-32J01		465958	1221900	I	615	170	8	O	-	-	-	Qc2?	-	35	580	05/01/1952	DR
18N/04E-33E01		470009	1221851	D	640	251	8	P 165-251	-	-	-	Qc3	-	46.3	594	06/22/1960	DGS
18N/04E-34B01		470030	1221659	-	690	142	6	-	-	-	-	Qc1	-	53.5	637	06/14/1960	DGR
18N/04E-34D01		470029	1221740	-	675	125	6	-	-	-	-		-	50	625	07/15/1952	DR
18N/04E-34G02		470019	1221649	P	745	232	8	P 190-230	400	4	34		82.2	95.3	650	06/29/1985	DR
18N/04E-34G01		470011	1221702	-	740	38.5	6	-	-	-	-		-	17.5	723	06/15/1960	DGS
18N/04E-34J01		470006	1221641	-	700	90	6	-	10	-	44		-	32.2	668	02/27/1951	DGR
18N/04E-36A01		470029	1221405	DI	690	66	6	O	18	-	50	Qvt	22	22	668	07/18/1980	DR
18N/04E-36K01	AFC095	465956	1221426	U	695	45	6	O	23	b 1	15		94	1.9	693	07/26/2000	DEFTW

Appendix B

Summary of water level and water quality data for instream piezometers and streams

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Appendix B - Summary of water level and water quality data for in-stream piezometers and streams within the Muck Creek Watershed, Pierce Co., WA.

Map ID [1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth [2] (feet)	Stream Level [3] (feet)	Vertical Hydraulic Gradient [4] (L/L)	Remarks
M1	Muck Ck at piezometer ECY-13	08/30/2000	12	98	-	-	-	-	-	
M1	Muck Ck at piezometer ECY-13	08/31/2000	11.7	98	-	-	-	-	-	
M1	Muck Ck at piezometer ECY-13	09/20/2000	10.3	-	11.5	-	6.2	3.54	-1.09	
M1	Muck Ck at piezometer ECY-13	10/25/2000	9.8	102	-	-	>6.95	3.65	>-1.35	Piezometer dry
M1	Muck Ck at piezometer ECY-13	11/28/2000	4.9	100	-	-	>6.95	3.84	>-1.27	Piezometer dry
M1	Muck Ck at piezometer ECY-13	12/22/2000	6.7	99	-	-	>6.95	3.91	>-1.24	Piezometer dry
M1	Muck Ck at piezometer ECY-13	01/10/2001	5.7	100	-	-	>6.95	3.9	>-1.24	Piezometer dry
M1	Muck Ck at piezometer ECY-13	02/07/2001	5.6	103	-	-	>6.95	3.64	>-1.35	Piezometer dry
M1	Muck Ck at piezometer ECY-13	03/05/2001	10.3	104	9.5	105	5.63	3.08	-1.04	
M1	Muck Ck at piezometer ECY-13	04/06/2001	9.9	108	-	-	>6.95	3	>-1.61	Piezometer dry
M1	Muck Ck at piezometer ECY-13	05/08/2001	13	104	-	-	>6.95	1.6	>-2.18	Piezometer dry
M1	Muck Ck at piezometer ECY-13	06/25/2001	12.9	101	-	-	>6.95	3.2	>-1.53	Piezometer dry
M4	Muck Ck at gage 12090200	08/24/1999	21.5	100	-	-	-	-	-	
M4	Muck Ck at gage 12090200	09/02/1999	15.1	94	-	-	-	-	-	
M4	Muck Ck at gage 12090200	12/14/1999	6.2	105	8.1	134	-	-	0.02*	
M4	Muck Ck at gage 12090200	12/21/1999	7.5	98	8.4	118	-	-	0.03*	
M4	Muck Ck at gage 12090200	01/20/2000	5.3	92	6.8	119	2.54	2.54	0.00	
M4	Muck Ck at gage 12090200	02/22/2000	8.1	108	8.1	134	2.6	2.6	0.00	
M4	Muck Ck at gage 12090200	03/23/2000	7.8	111	7.8	112	2.2	2.2	0.00	
M4	Muck Ck at gage 12090200	04/26/2000	10.4	84	10.1	101	3.04	3.04	0.00	
M4	Muck Ck at gage 12090200	05/24/2000	14.2	89	12.2	104	3.46	3.48	0.01	
M4	Muck Ck at gage 12090200	06/06/2000	-	-	-	-	3.67	3.7	0.01	
M4	Muck Ck at gage 12090200	06/07/2000	15.1	91	-	-	-	-	NA	
M4	Muck Ck at gage 12090200	06/30/2000	-	-	-	-	4.11	4.07	-0.02	
M4	Muck Ck at gage 12090200	07/27/2000	16.5	131	17.2	123	4.35	4.35	0.00	
M4	Muck Ck at gage 12090200	08/17/2000	-	-	-	-	5.41	-	-	Ck dry, piezometer has water
M4	Muck Ck at gage 12090200	08/31/2000	-	-	14.8	126	5.8	-	-	Ck dry, piezometer has water
M4	Muck Ck at gage 12090200	09/21/2000	-	-	15	125	6.13	-	-	Ck dry, piezometer has water
M4	Muck Ck at gage 12090200	10/25/2000	7.8	143	8.6	148	4.3	4.31	0.01	
M4	Muck Ck at gage 12090200	11/28/2000	2.1	158	3	163	3.99	3.95	-0.02	
M4	Muck Ck at gage 12090200	12/22/2000	3.9	183	3.5	185	3.61	3.53	-0.03	
M4	Muck Ck at gage 12090200	01/10/2001	3.5	185	4.7	189	3.81	3.81	0.00	
M4	Muck Ck at gage 12090200	02/07/2001	3.1	131	5.1	148	3.52	3.52	0.00	
M4	Muck Ck at gage 12090200	03/05/2001	6.8	112	6.9	129	3.49	3.51	0.01	
M4	Muck Ck at gage 12090200	04/06/2001	7.9	129	8.7	133	3.62	3.64	0.01	
M4	Muck Ck at gage 12090200	05/09/2001	13.2	102	10.6	135	3.29	3.31	0.01	
M4	Muck Ck at gage 12090200	06/25/2001	16	103	14.9	113	3.86	3.86	0.00	

Appendix B - Summary of water level and water quality data for in-stream piezometers and streams within the Muck Creek Watershed, Pierce Co., WA.

Map ID [1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth [2] (feet)	Stream Level [3] (feet)	Vertical Hydraulic Gradient [4] (L/L)	Remarks
M11	Muck Ck at Hwy 507	12/21/1999	6.9	87	7.3	95	-	-	-0.02*	
M11	Muck Ck at Hwy 507	01/20/2000	3.1	92	3.1	91	3.45	3.42	-0.01	
M11	Muck Ck at Hwy 507	02/22/2000	6.6	105	6.6	105	3.05	2.94	-0.05	
M11	Muck Ck at Hwy 507	03/23/2000	6.7	97	7.1	98	3.1	2.52	-0.26	
M11	Muck Ck at Hwy 507	04/26/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	05/04/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	05/24/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	06/06/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	06/30/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	07/13/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	07/27/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	08/17/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	08/31/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	09/19/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	10/25/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	11/28/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	12/22/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	01/10/2001	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	02/07/2001	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	03/05/2001	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	04/06/2001	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	05/08/2001	-	-	-	-	-	-	-	Piezometer and Ck dry
M11	Muck Ck at Hwy 507	06/25/2001	-	-	-	-	-	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	08/31/2000	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	09/19/2000	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	10/25/2000	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	11/28/2000	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	12/22/2000	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	01/10/2001	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	02/07/2001	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	03/05/2001	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	04/06/2001	7.20	95	7.4	95	4.2	4.12	-0.05	
M12	Muck Ck at piezometer HEC-12	05/08/2001	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M12	Muck Ck at piezometer HEC-12	06/25/2001	-	-	-	-	>6.8	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	01/20/2000	3.6	92	3.6	92	4.37	2.36	-0.68	

Appendix B - Summary of water level and water quality data for in-stream piezometers and streams within the Muck Creek Watershed, Pierce Co., WA.

Map ID[1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth[2] (feet)	Stream Level[3] (feet)	Vertical Hydraulic Gradient[4] (L/L)	Remarks
M13	Muck Ck at piezometer ECY-3	02/22/2000	6.8	107	6.8	108	4.87	2.3	-0.87	
M13	Muck Ck at piezometer ECY-3	03/23/2000	6.7	96	7.3	100	5.35	1.77	-1.21	
M13	Muck Ck at piezometer ECY-3	04/26/2000	9.3	99	12.5	103	6.5	2.94	-1.21	
M13	Muck Ck at piezometer ECY-3	05/24/2000	14.1	109	-	-	>6.7	3.4	>-1.12	Piezometer dry, flow in Ck
M13	Muck Ck at piezometer ECY-3	06/06/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	06/30/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	07/27/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	08/17/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	08/31/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	09/19/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	10/25/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	11/28/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	12/22/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	01/10/2001	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	02/07/2001	1.9	103	2.3	94	4.34	3.04	-0.44	
M13	Muck Ck at piezometer ECY-3	03/05/2001	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M13	Muck Ck at piezometer ECY-3	04/06/2001	7.2	95	7.3	95	4.7	2.53	-0.74	
M13	Muck Ck at piezometer ECY-3	05/08/2001	12.1	111	-	-	>6.7	3.25	>-1.17	Piezometer dry, flow in Ck
M13	Muck Ck at piezometer ECY-3	06/25/2001	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M14	Muck Ck at piezometer ECY-4	01/12/2000	3.1	79	3.8	87	-	-	-0.45*	
M14	Muck Ck at piezometer ECY-4	01/20/2000	3.7	92	3.6	92	5.1	2.48	-0.95	
M14	Muck Ck at piezometer ECY-4	02/22/2000	6.8	108	-	-	>6.7	2.6	>-1.49	Piezometer Dry, flow in Ck
M14	Muck Ck at piezometer ECY-4	03/23/2000	7	96	8.4	104	4.98	1.9	-1.12	Ck outside banks
M14	Muck Ck at piezometer ECY-4	04/26/2000	9.1	99	-	-	>6.7	3.27	>-1.25	Piezometer dry
M14	Muck Ck at piezometer ECY-4	05/24/2000	12.8	112	-	-	>6.7	3.58	>-1.13	Piezometer dry
M14	Muck Ck at piezometer ECY-4	06/06/2000	-	-	-	-	>6.7	3.86	>-1.03	Piezometer dry
M14	Muck Ck at piezometer ECY-4	06/15/2000	-	-	-	-	>6.7	3.5	>-1.16	Piezometer dry
M14	Muck Ck at piezometer ECY-4	06/30/2000	-	-	-	-	>6.7	-	-	Piezometer outside channel, flow in Ck
M14	Muck Ck at piezometer ECY-4	07/27/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M14	Muck Ck at piezometer ECY-4	08/17/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M14	Muck Ck at piezometer ECY-4	08/31/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M14	Muck Ck at piezometer ECY-4	09/19/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M14	Muck Ck at piezometer ECY-4	10/25/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M14	Muck Ck at piezometer ECY-4	11/28/2000	-	-	-	-	>6.7	-	-	Piezometer and Ck dry
M14	Muck Ck at piezometer ECY-4	12/22/2000	4.2	120	-	-	>6.7	3.53	>-1.15	
M14	Muck Ck at piezometer ECY-4	01/10/2001	3.8	112	-	-	>6.7	3.21	>-1.27	
M14	Muck Ck at piezometer ECY-4	02/07/2001	2	103	-	-	>6.7	2.85	>-1.40	Piezometer dry

Appendix B - Summary of water level and water quality data for in-stream piezometers and streams within the Muck Creek Watershed, Pierce Co., WA.

Map ID [1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth [2] (feet)	Stream Level [3] (feet)	Vertical Hydraulic Gradient [4] (L/L)	Remarks
M14	Muck Ck at piezometer ECY-4	03/05/2001	5.4	117	-	-	>6.7	3.31	>-1.23	Piezometer dry
M14	Muck Ck at piezometer ECY-4	04/06/2001	7.1	95	-	-	>6.7	2.8	>-1.42	Piezometer dry
M14	Muck Ck at piezometer ECY-4	05/08/2001	11.6	112	-	-	>6.7	3.27	>-1.25	Piezometer dry
M14	Muck Ck at piezometer ECY-4	06/25/2001	13.1	136	-	-	>6.7	3.75	>-1.07	Piezometer dry
M15	Muck Ck at piezometer HEC-9	08/31/2000	14.8	144	-	-	>6.78	2.78	>-1.04	Piezometer dry
M15	Muck Ck at piezometer HEC-9	09/19/2000	-	-	-	-	>6.78	2.69	>-1.06	Piezometer dry
M15	Muck Ck at piezometer HEC-9	09/21/2000	14	142	-	-	>6.78	-	NA	Piezometer dry
M15	Muck Ck at piezometer HEC-9	10/25/2000	7.5	143	-	-	>6.78	2.76	>-1.04	Piezometer dry
M15	Muck Ck at piezometer HEC-9	11/28/2000	2.1	125	-	-	6.39	2.44	-1.03	
M15	Muck Ck at piezometer HEC-9	12/22/2000	4.2	121	4.6	155	5.11	2.38	-0.71	
M15	Muck Ck at piezometer HEC-9	01/10/2001	3.8	114	4.9	94	3.97	1.83	-0.56	
M15	Muck Ck at piezometer HEC-9	02/07/2001	2	104	5	99	2.79	1.08	-0.44	
M15	Muck Ck at piezometer HEC-9	03/05/2001	5.4	118	5.1	113	5.65	2.11	-0.92	
M15	Muck Ck at piezometer HEC-9	04/06/2001	7.1	95	7.1	99	2.53	0.82	-0.44	
M15	Muck Ck at piezometer HEC-9	05/08/2001	11.5	112	11.6	126	5.5	1.75	-0.97	
M15	Muck Ck at piezometer HEC-9	06/25/2001	12.8	139	-	-	>6.78	2.46	>-1.12	Piezometer dry
M16	Muck Ck at piezometer HEC-7	08/17/2000	-	-	-	-	>6.93	2.98	>-1.14	Piezometer dry
M16	Muck Ck at piezometer HEC-7	08/31/2000	14.7	143	-	-	>6.93	2.98	>-1.14	Piezometer dry
M16	Muck Ck at piezometer HEC-7	09/19/2000	-	-	-	-	>6.93	2.96	>-1.15	Piezometer dry
M16	Muck Ck at piezometer HEC-7	09/21/2000	14	142	-	-	>6.93	2.95	>-1.15	Piezometer dry
M16	Muck Ck at piezometer HEC-7	10/25/2000	7.7	144	-	-	>6.93	2.85	>-1.18	Piezometer dry
M16	Muck Ck at piezometer HEC-7	11/28/2000	2.6	121	-	-	>6.93	2.38	>-1.32	Piezometer dry
M16	Muck Ck at piezometer HEC-7	12/22/2000	4.4	124	3.3	121	5.69	2.41	-0.95	
M16	Muck Ck at piezometer HEC-7	01/10/2001	4	113	5.2	105	3.93	1.95	-0.57	
M16	Muck Ck at piezometer HEC-7	02/07/2001	2.2	103	4.7	112	2.74	1.35	-0.40	
M16	Muck Ck at piezometer HEC-7	03/05/2001	5.6	121	-	-	>6.93	2.2	>-1.37	Piezometer dry
M16	Muck Ck at piezometer HEC-7	04/06/2001	7.1	95	7.5	109	2.84	1.06	-0.52	
M16	Muck Ck at piezometer HEC-7	05/08/2001	11.5	112	12.8	112	6.35	2.01	-1.26	
M16	Muck Ck at piezometer HEC-7	06/25/2001	12.9	142	-	-	>6.93	2.73	>-1.22	Piezometer dry
M17	Muck Ck at piezometer ECY-5	01/12/2000	4.4	83	5.4	97	-	-	-0.01*	
M17	Muck Ck at piezometer ECY-5	01/20/2000	4	92	5.9	92	1.42	1.3	-0.04	
M17	Muck Ck at piezometer ECY-5	02/22/2000	6.9	109	5.8	94	1.75	1.5	-0.09	
M17	Muck Ck at piezometer ECY-5	03/23/2000	7.3	97	8	120	0.72	0.62	-0.04	
M17	Muck Ck at piezometer ECY-5	04/26/2000	9.3	98	11.3	100	3.61	2.66	-0.35	
M17	Muck Ck at piezometer ECY-5	05/24/2000	12.6	111	14.3	113	5.5	3.02	-0.90	

Appendix B - Summary of water level and water quality data for in-stream piezometers and streams within the Muck Creek Watershed, Pierce Co., WA.

Map ID[1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth[2] (feet)	Stream Level[3] (feet)	Vertical Hydraulic Gradient[4] (L/L)	Remarks
M17	Muck Ck at piezometer ECY-5	06/30/2000	-	-	-	-	>6.63	3.55	>-1.12	Piezometer dry
M17	Muck Ck at piezometer ECY-5	07/27/2000	17.3	138	-	-	>6.63	3.66	>-1.08	Piezometer dry
M17	Muck Ck at piezometer ECY-5	08/17/2000	13.7	149	-	-	>6.63	3.7	>-1.07	Piezometer dry
M17	Muck Ck at piezometer ECY-5	08/31/2000	14.7	143	-	-	>6.63	3.69	>-1.07	Piezometer dry
M17	Muck Ck at piezometer ECY-5	09/19/2000	-	-	-	-	>6.63	3.68	>-1.07	Piezometer dry
M17	Muck Ck at piezometer ECY-5	09/21/2000	14.1	139	-	-	-	-	NA	
M17	Muck Ck at piezometer ECY-5	10/25/2000	7.7	143	-	-	>6.63	3.63	>-1.09	Piezometer dry
M17	Muck Ck at piezometer ECY-5	11/28/2000	2.7	116	-	-	>6.63	3.13	>-1.27	Piezometer dry
M17	Muck Ck at piezometer ECY-5	12/22/2000	4.5	123	-	-	>6.63	3.18	>-1.25	Piezometer dry
M17	Muck Ck at piezometer ECY-5	01/10/2001	4.1	115	4.7	96	3.87	2.66	-0.44	
M17	Muck Ck at piezometer ECY-5	02/07/2001	2.2	101	5.4	97	2.61	1.98	-0.23	
M17	Muck Ck at piezometer ECY-5	03/05/2001	5.8	120	5.2	112	6.05	3.02	-1.10	
M17	Muck Ck at piezometer ECY-5	04/06/2001	7.2	94	7.1	100	2.17	1.57	-0.22	
M17	Muck Ck at piezometer ECY-5	05/08/2001	12	111	11.7	109	4.3	2.73	-0.57	
M17	Muck Ck at piezometer ECY-5	06/25/2001	12.8	142	-	-	>6.63	3.48	>-1.15	Piezometer dry
M18	Muck Ck at 8th Ave S	08/24/1999	15.2	140	-	-	-	-	-	
M18	Muck Ck at 8th Ave S	09/02/1999	11.1	138	-	-	-	-	-	
M18	Muck Ck at 8th Ave S	01/12/2000	3.5	81	3.8	83	-	-	-0.11*	
M18	Muck Ck at 8th Ave S	01/20/2000	4	91	4.1	92	3.21	2.35	-0.46	
M18	Muck Ck at 8th Ave S	02/22/2000	6.7	100	6.4	98	3.81	2.62	-0.64	
M18	Muck Ck at 8th Ave S	03/23/2000	7	94	7.6	109	2.27	1.59	-0.37	Ck running bank full
M18	Muck Ck at 8th Ave S	04/26/2000	9.4	99	10.7	99	5.16	3.74	-0.77	
M18	Muck Ck at 8th Ave S	05/24/2000	13	111	14.9	106	6.14	4.09	-1.11	
M18	Muck Ck at 8th Ave S	06/06/2000	14.2	132	-	-	>6.84	4.39	>-1.32	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	06/30/2000	18.1	138	-	-	>6.84	4.51	>-1.26	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	07/13/2000	16.6	142	-	-	>6.84	4.54	>-1.24	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	07/27/2000	17.2	140	-	-	>6.84	4.65	>-1.18	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	08/17/2000	13.7	156	-	-	>6.84	4.68	>-1.17	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	08/31/2000	14.6	143	-	-	>6.84	-		Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	09/19/2000			-	-	>6.84	4.68	>-1.17	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	09/21/2000	14	139	-	-	>6.84	4.68	>-1.17	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	10/25/2000	7.5	143	-	-	>6.84	4.6	>-1.21	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	11/28/2000	2.7	113	-	-	>6.84	4.04	>-1.51	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	12/22/2000	4.5	123	-	-	>6.84	4.12	>-1.47	Piezometer dry, Ck has water
M18	Muck Ck at 8th Ave S	01/10/2001	4	114	4.7	111	5.45	3.77	-0.91	
M18	Muck Ck at 8th Ave S	02/07/2001	2.1	104	4.7	106	4.64	3.18	-0.79	
M18	Muck Ck at 8th Ave S	03/05/2001	5.7	120	-	-	>6.84	4.1	>-1.48	Piezometer dry, Ck has water

Appendix B - Summary of water level and water quality data for in-stream piezometers and streams within the Muck Creek Watershed, Pierce Co., WA.

Map ID [1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth [2] (feet)	Stream Level [3] (feet)	Vertical Hydraulic Gradient [4] (L/L)	Remarks
M18	Muck Ck at 8th Ave S	04/06/2001	7.2	94	7.4	96	4.15	2.87	-0.69	
M18	Muck Ck at 8th Ave S	05/08/2001	11.8	112	12.3	111	5.58	3.87	-0.92	
M18	Muck Ck at 8th Ave S	06/25/2001	12.6	143	-	-	>6.84	4.47	>-1.28	Piezometer dry, Ck has water
M19	Muck Ck at piezometer HEC-6	09/19/2000	-	-	-	-	>5.95	3.33	>-0.86	Piezometer dry
M19	Muck Ck at piezometer HEC-6	09/21/2000	14.2	140	-	-	>5.95	3.33	>-0.86	Piezometer dry
M19	Muck Ck at piezometer HEC-6	10/25/2000	8.1	143	-	-	>5.95	3.21	>-0.90	Piezometer dry
M19	Muck Ck at piezometer HEC-6	11/28/2000	2.9	113	-	-	>5.95	2.9	>-1.00	Piezometer dry
M19	Muck Ck at piezometer HEC-6	12/22/2000	4.7	124	-	-	5.72	2.97	-0.90	Piezometer dry
M19	Muck Ck at piezometer HEC-6	01/10/2001	4.3	114	6.6	110	3.49	2.69	-0.26	
M19	Muck Ck at piezometer HEC-6	02/07/2001	2.3	101	5.7	105	3.32	2.24	-0.35	
M19	Muck Ck at piezometer HEC-6	03/05/2001	6.2	119	6.3	111	4.78	2.9	-0.62	
M19	Muck Ck at piezometer HEC-6	04/06/2001	7.3	94	7.8	120	2.94	1.9	-0.34	
M19	Muck Ck at piezometer HEC-6	05/08/2001	12.4	112	10.4	153	3.5	2.76	-0.24	
M19	Muck Ck at piezometer HEC-6	06/25/2001	13	142	-	-	>5.95	3.2	>-0.90	Piezometer dry
M20	Muck Ck at piezometer HEC-2	09/19/2000	-	-	-	-	>7	2.94	>-1.33	Piezometer dry
M20	Muck Ck at piezometer HEC-2	09/21/2000	13.8	142	-	-	>7	2.94	>-1.33	Piezometer dry
M20	Muck Ck at piezometer HEC-2	10/25/2000	7.8	145	-	-	>7	2.85	>-1.36	Piezometer dry
M20	Muck Ck at piezometer HEC-2	12/22/2000	5.5	137	-	-	>7	2.79	>-1.38	Piezometer dry
M20	Muck Ck at piezometer HEC-2	01/10/2001	5.2	135	6	119	5.49	2.76	-0.89	
M20	Muck Ck at piezometer HEC-2	02/07/2001	2.7	131	5.4	116	5.45	2.74	-0.89	
M20	Muck Ck at piezometer HEC-2	03/05/2001	7.5	138	-	-	>7	2.8	>-1.38	Piezometer dry
M20	Muck Ck at piezometer HEC-2	04/06/2001	8.1	125	7.3	111	5.18	2.7	-0.81	
M20	Muck Ck at piezometer HEC-2	05/08/2001	12.7	135	10.2	101	5.82	2.76	-1.00	
M20	Muck Ck at piezometer HEC-2	06/25/2001	12.8	142	-	-	>7	2.85	>-1.36	Piezometer dry
M21	Muck Ck at piezometer HEC-1	09/19/2000	-	-	-	-	5.5	3.14	-0.77	
M21	Muck Ck at piezometer HEC-1	09/21/2000	13.8	142	-	-	5.44	3.14	-0.75	
M21	Muck Ck at piezometer HEC-1	10/25/2000	7.7	145	8.9	144	5.49	3.03	-0.81	
M21	Muck Ck at piezometer HEC-1	11/28/2000	3.0	122	4.0	123	5.24	2.8	-0.80	
M21	Muck Ck at piezometer HEC-1	12/22/2000	5.6	137	4.3	137	4.76	2.74	-0.66	
M21	Muck Ck at piezometer HEC-1	01/10/2001	5.5	135	5.9	136	3.85	2.63	-0.40	
M21	Muck Ck at piezometer HEC-1	02/07/2001	3.1	132	5.5	132	4.09	2.61	-0.49	
M21	Muck Ck at piezometer HEC-1	03/05/2001	8.7	137	6.1	137	5.02	2.81	-0.72	
M21	Muck Ck at piezometer HEC-1	04/06/2001	8.3	124	8.2	130	4.23	2.55	-0.55	
M21	Muck Ck at piezometer HEC-1	05/08/2001	12.7	135	11.5	135	4.53	2.73	-0.59	
M21	Muck Ck at piezometer HEC-1	06/25/2001	13.2	141	15	141	5.32	2.87	-0.80	

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Map ID[1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth[2] (feet)	Stream Level[3] (feet)	Vertical Hydraulic Gradient[4] (L/L)	Remarks
M22	Muck Ck at 8th Ave E	09/02/1999	15.1	134	-	-	-	-	-	
M22	Muck Ck at 8th Ave E	12/14/1999	6.6	105	8.6	115	-	-	0.18*	
M22	Muck Ck at 8th Ave E	12/21/1999	7.3	108	9.3	106	-	-	0.19*	
M22	Muck Ck at 8th Ave E	01/20/2000	4.8	114	8.2	108	1.15	1.6	0.11	
M22	Muck Ck at 8th Ave E	02/22/2000	7.3	133	7.8	107	1.29	1.64	0.09	
M22	Muck Ck at 8th Ave E	03/23/2000	7.8	127	8.1	118	1.1	1.5	0.10	
M22	Muck Ck at 8th Ave E	04/26/2000	9.8	118	9.2	115	1.56	1.74	0.05	
M22	Muck Ck at 8th Ave E	05/24/2000	13.6	124	11.3	126	1.8	1.82	0.01	
M22	Muck Ck at 8th Ave E	06/06/2000	14	133	-	-	1.98	1.9	-0.02	
M22	Muck Ck at 8th Ave E	06/30/2000	17.2	133	-	-	2.16	1.98	-0.05	
M22	Muck Ck at 8th Ave E	07/13/2000	15.2	138	-	-	2.37	2.01	-0.09	
M22	Muck Ck at 8th Ave E	07/27/2000	16.1	142	17.1	133	2.78	2.07	-0.18	
M22	Muck Ck at 8th Ave E	08/17/2000	13.7	145	-	-	3.4	2.06	-0.34	
M22	Muck Ck at 8th Ave E	08/31/2000	14.5	147	15	142	3.66	1.98	-0.43	
M22	Muck Ck at 8th Ave E	09/19/2000	-	-	-	-	3.83	1.92	-0.48	
M22	Muck Ck at 8th Ave E	09/21/2000	13.4	150	14.8	143	3.82	1.92	-0.48	
M22	Muck Ck at 8th Ave E	10/25/2000	8.1	144	9.4	143	3.46	1.99	-0.37	
M22	Muck Ck at 8th Ave E	11/28/2000	3.7	123	4	128	2.73	1.91	-0.21	
M22	Muck Ck at 8th Ave E	12/22/2000	5.7	137	7.5	139	1.65	1.9	0.06	
M22	Muck Ck at 8th Ave E	01/10/2001	5.2	135	8.2	137	1.47	1.86	0.10	
M22	Muck Ck at 8th Ave E	02/07/2001	3.4	132	8	127	1.63	1.88	0.06	
M22	Muck Ck at 8th Ave E	03/05/2001	8.8	137	8.3	121	1.95	1.95	0.00	
M22	Muck Ck at 8th Ave E	04/06/2001	8.4	125	8.6	127	1.53	1.81	0.07	
M22	Muck Ck at 8th Ave E	05/08/2001	13.1	136	10.7	122	1.64	1.87	0.06	
M22	Muck Ck at 8th Ave E	06/25/2001	13.4	141	11.9	129	2.09	2.02	-0.02	
M23	Muck Ck at Weiler Rd	08/24/1999	14.6	148	-	-	-	-	-	
M23	Muck Ck at Weiler Rd	09/02/1999	11.8	149	-	-	-	-	-	
M23	Muck Ck at Weiler Rd	09/21/1999	13.6	149	-	-	-	-	-	
M23	Muck Ck at Weiler Rd	12/14/1999	5.9	109	8.8	161	-	-	0.12*	
M23	Muck Ck at Weiler Rd	12/21/1999	6.4	118	8.9	162	-	-	0.12*	
M23	Muck Ck at Weiler Rd	01/20/2000	3.9	120	7.9	167	0.64	1.2	0.13	
M23	Muck Ck at Weiler Rd	02/22/2000	6.8	120	7.7	167	0.72	1.3	0.14	
M23	Muck Ck at Weiler Rd	03/23/2000	7.1	111	8.2	163	0.55	1.15	0.14	
M23	Muck Ck at Weiler Rd	04/26/2000	9.1	124	9.8	159	0.93	1.52	0.14	
M23	Muck Ck at Weiler Rd	05/24/2000	11.6	132	10.8	157	1.1	1.63	0.13	
M23	Muck Ck at Weiler Rd	06/06/2000	12.3	140	-	-	1.2	1.67	0.11	

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M23	Muck Ck at Weiler Rd	06/28/2000	16.1	144	-	-	1.44	1.71	0.07	
M23	Muck Ck at Weiler Rd	07/13/2000	13.8	146	-	-	1.23	1.67	0.11	
M23	Muck Ck at Weiler Rd	07/27/2000	15.2	151	12.9	189	1.48	1.72	0.06	
M23	Muck Ck at Weiler Rd	08/17/2000	13.3	152	-	-	2.17	1.83	-0.08	
M23	Muck Ck at Weiler Rd	08/31/2000	13.6	152	13	173	2.09	1.81	-0.07	
M23	Muck Ck at Weiler Rd	09/19/2000	-	-	-	-	2.17	1.8	-0.09	
M23	Muck Ck at Weiler Rd	09/21/2000	12.6	150	12.6	153	2.14	1.8	-0.08	
M23	Muck Ck at Weiler Rd	10/25/2000	8.4	148	11.1	177	1.59	1.74	0.04	
M23	Muck Ck at Weiler Rd	11/28/2000	3.7	131	8.3	173	0.99	1.52	0.13	
M23	Muck Ck at Weiler Rd	12/22/2000	5.8	141	8	177	0.97	1.57	0.14	
M23	Muck Ck at Weiler Rd	01/10/2001	5	141	8.3	176	0.93	1.56	0.15	
M23	Muck Ck at Weiler Rd	02/07/2001	2.7	139	7.8	173	0.91	1.58	0.16	
M23	Muck Ck at Weiler Rd	03/05/2001	8.4	143	8.6	177	1.07	1.62	0.13	
M23	Muck Ck at Weiler Rd	04/06/2001	8	128	8.6	170	0.61	1.33	0.17	
M23	Muck Ck at Weiler Rd	05/08/2001	11	145	9.6	164	0.92	1.5	0.14	
M23	Muck Ck at Weiler Rd	06/25/2001	12.5	150	11.3	164	1.28	1.4	0.03	
M24	Muck Ck at 70th Ave E	08/24/1999	14.1	152	-	-	-	-	-	
M24	Muck Ck at 70th Ave E	09/02/1999	11.7	153	-	-	-	-	-	
M24	Muck Ck at 70th Ave E	12/14/1999	5.8	115	-	-	-	-	-	
M24	Muck Ck at 70th Ave E	12/21/1999	6.3	120	8.9	203	-	-	-0.04*	
M24	Muck Ck at 70th Ave E	01/20/2000	3.9	123	7.4	202	1.61	1.15	-0.10	
M24	Muck Ck at 70th Ave E	02/22/2000	7.1	121	7.2	196	1.66	1.1	-0.13	
M24	Muck Ck at 70th Ave E	03/23/2000	8.1	114	7.9	180	1.3	1.02	-0.06	
M24	Muck Ck at 70th Ave E	04/26/2000	11.1	124	9.7	154	2.35	1.3	-0.24	
M24	Muck Ck at 70th Ave E	05/24/2000	15.5	129	11.3	145	2.58	1.43	-0.26	
M24	Muck Ck at 70th Ave E	06/06/2000	12.2	139	-	-	2.78	1.53	-0.28	
M24	Muck Ck at 70th Ave E	06/28/2000	16.8	146	-	-	2.92	1.55	-0.31	
M24	Muck Ck at 70th Ave E	07/13/2000	11.9	153	-	-	2.99	1.53	-0.33	
M24	Muck Ck at 70th Ave E	07/26/2000	13.3	154	13.3	152	3.08	1.61	-0.33	
M24	Muck Ck at 70th Ave E	08/17/2000	16.1	157	-	-	3.3	1.72	-0.36	
M24	Muck Ck at 70th Ave E	08/30/2000	13.3	160	13.6	152	3.25	1.72	-0.34	
M24	Muck Ck at 70th Ave E	09/19/2000	-	-	-	-	3.2	1.71	-0.33	
M24	Muck Ck at 70th Ave E	09/21/2000	12.9	155	13.2	148	3.21	1.71	-0.34	
M24	Muck Ck at 70th Ave E	10/25/2000	8.4	156	11.2	157	2.92	1.58	-0.30	
M24	Muck Ck at 70th Ave E	11/28/2000	3.8	145	8.1	169	2.36	1.43	-0.21	
M24	Muck Ck at 70th Ave E	12/22/2000	6.3	147	7.6	169	2.57	1.44	-0.25	
M24	Muck Ck at 70th Ave E	01/10/2001	5.7	146	7.9	174	2.46	1.42	-0.23	

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Map ID [1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth [2] (feet)	Stream Level [3] (feet)	Vertical Hydraulic Gradient [4] (L/L)	Remarks
M24	Muck Ck at 70th Ave E	02/07/2001	4.7	146	7.2	187	2.34	1.46	-0.20	
M24	Muck Ck at 70th Ave E	03/05/2001	10.6	146	7.7	171	2.73	1.49	-0.28	
M24	Muck Ck at 70th Ave E	04/06/2001	9.1	136	8.4	194	2.12	1.36	-0.17	
M24	Muck Ck at 70th Ave E	05/08/2001	13.7	145	9.9	180	2.46	1.37	-0.25	
M24	Muck Ck at 70th Ave E	06/25/2001	15	153	12.1	169	2.76	1.45	-0.29	
L5	Lacamas Ck at 8th Ave S	08/24/1999	12.8	170	-	-	-	-	-	
L5	Lacamas Ck at 8th Ave S	09/02/1999	11.5	170	-	-	-	-	-	
L5	Lacamas Ck at 8th Ave S	12/21/1999	6.7	120	-	-	-	-	-	
L5	Lacamas Ck at 8th Ave S	01/20/2000	4.3	113	-	-	1.24	1.33	0.02	
L5	Lacamas Ck at 8th Ave S	02/22/2000	7.5	115	-	-	1.41	1.48	0.02	
L5	Lacamas Ck at 8th Ave S	03/23/2000	9.9	138	-	-	1.43	1.58	0.03	
L5	Lacamas Ck at 8th Ave S	04/26/2000	13.9	143	-	-	1.66	1.82	0.04	
L5	Lacamas Ck at 8th Ave S	05/24/2000	15.4	158	-	-	1.75	1.86	0.03	
L5	Lacamas Ck at 8th Ave S	06/07/2000	12.2	162	-	-	1.71	1.83	0.03	
L5	Lacamas Ck at 8th Ave S	06/30/2000	15.9	166	-	-	1.65	1.71	0.01	
L5	Lacamas Ck at 8th Ave S	07/13/2000	16.6	165	-	-	1.61	1.67	0.01	
L5	Lacamas Ck at 8th Ave S	07/27/2000	16.9	167	-	-	1.57	1.6	0.01	
L5	Lacamas Ck at 8th Ave S	08/17/2000	16.7	168	-	-	1.74	1.75	0.00	
L5	Lacamas Ck at 8th Ave S	08/31/2000	12.8	170	-	-	1.61	1.64	0.01	
L5	Lacamas Ck at 8th Ave S	09/20/2000	12.3	-	-	-	1.48	1.53	0.01	
L5	Lacamas Ck at 8th Ave S	10/25/2000	9.3	168	-	-	1.3	1.37	0.02	
L5	Lacamas Ck at 8th Ave S	11/28/2000	4.9	150	-	-	1.07	1.16	0.02	
L5	Lacamas Ck at 8th Ave S	12/22/2000	6.7	155	-	-	1.21	1.27	0.01	
L5	Lacamas Ck at 8th Ave S	01/10/2001	6.2	150	-	-	1.24	1.36	0.03	
L5	Lacamas Ck at 8th Ave S	02/07/2001	4.2	134	-	-	1.19	1.3	0.03	
L5	Lacamas Ck at 8th Ave S	03/05/2001	10.4	147	-	-	1.44	1.57	0.03	
L5	Lacamas Ck at 8th Ave S	04/06/2001	8.8	126	-	-	1.35	1.49	0.03	
L5	Lacamas Ck at 8th Ave S	05/08/2001	15	152	-	-	1.63	1.81	0.04	
L5	Lacamas Ck at 8th Ave S	06/25/2001	16.3	165	-	-	1.69	1.77	0.02	
S1	South Creek at 8th Ave E	01/12/2000	3.1	75	3.9	80	-	-	-0.11*	
S1	South Creek at 8th Ave E	01/20/2000	3.1	83	2.7	82	2.13	1.6	-0.17	
S1	South Creek at 8th Ave E	02/22/2000	6.3	80	6	80	2.78	1.93	-0.28	
S1	South Creek at 8th Ave E	03/23/2000	7	69	7.6	78	1.06	0.72	-0.11	Ck flowing bank full
S1	South Creek at 8th Ave E	04/26/2000	11.2	81	11.4	78	4.35	2.93	-0.47	
S1	South Creek at 8th Ave E	05/24/2000	16.4	87	16.6	93	5.8	3.37	-0.80	
S1	South Creek at 8th Ave E	06/07/2000	15.6	101	-	-	6.39	-	NA	Piezometer outside channel

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Map ID [1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth [2] (feet)	Stream Level [3] (feet)	Vertical Hydraulic Gradient [4] (L/L)	Remarks
S1	South Creek at 8th Ave E	06/30/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
S1	South Creek at 8th Ave E	07/13/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
S1	South Creek at 8th Ave E	07/27/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
S1	South Creek at 8th Ave E	08/17/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
S1	South Creek at 8th Ave E	08/31/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
S1	South Creek at 8th Ave E	09/19/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
S1	South Creek at 8th Ave E	10/25/2000	-	-	-	-	-	-	-	Piezometer and Ck dry
S1	South Creek at 8th Ave E	11/28/2000	3.7	102	3.8	99	5.77	2.63	-1.03	
S1	South Creek at 8th Ave E	12/22/2000	5.1	109	3.7	112	4.21	3.04	-0.38	
S1	South Creek at 8th Ave E	01/10/2001	4.7	104	4.5	102	3.24	2.45	-0.26	
S1	South Creek at 8th Ave E	02/07/2001	2.9	94	3.6	100	2.95	1.76	-0.39	
S1	South Creek at 8th Ave E	03/05/2001	8.7	99	5.9	101	5.37	3.17	-0.72	
S1	South Creek at 8th Ave E	04/06/2001	7.6	86	7.6	90	2.9	1.4	-0.49	
S1	South Creek at 8th Ave E	05/08/2001	14.4	91	13.1	94	4.72	3.1	-0.53	
S1	South Creek at 8th Ave E	06/25/2001	15.7	96	-	-	-	-	NA	Piezometer dry,outside channel
S3	South Creek near 294th St E	02/04/2000	4.1	76	6.4	149	0.33	1.2	0.28	
S3	South Creek near 294th St E	02/22/2000	6.5	79	7	135	0.81	1.68	0.28	
S3	South Creek near 294th St E	03/23/2000	7.9	84	8.2	173	-0.02	0.67	0.22	Piezometer flowing
S3	South Creek near 294th St E	04/26/2000	10.9	80	10.6	146	1.44	2.58	0.36	
S3	South Creek near 294th St E	05/24/2000	14.7	92	11.9	145	1.86	2.95	0.35	
S3	South Creek near 294th St E	06/07/2000	13.5	102	-	-	2.1	3.21	0.35	
S3	South Creek near 294th St E	06/30/2000	16.9	112	-	-	2.33	3.42	0.35	
S3	South Creek near 294th St E	07/13/2000	16.2	115	-	-	2.45	3.46	0.32	
S3	South Creek near 294th St E	07/27/2000	17.2	122	14.6	138	2.6	3.52	0.29	
S3	South Creek near 294th St E	08/17/2000	14.9	132	-	-	2.74	3.59	0.27	
S3	South Creek near 294th St E	08/31/2000	13.8	136	13.1	133	2.73	3.57	0.27	
S3	South Creek near 294th St E	09/20/2000	14	-	-	-	2.72	3.55	0.26	
S3	South Creek near 294th St E	09/21/2000	14.2	135	12.6	123	2.72	3.54	0.26	
S3	South Creek near 294th St E	10/25/2000	7.6	132	10.4	130	2.54	3.33	0.25	
S3	South Creek near 294th St E	11/28/2000	3.4	104	6.7	130	1.71	2.24	0.17	
S3	South Creek near 294th St E	12/22/2000	4.8	110	6.5	133	1.97	2.59	0.20	
S3	South Creek near 294th St E	01/10/2001	4.5	104	6.8	132	1.73	2.34	0.19	
S3	South Creek near 294th St E	02/07/2001	2.7	96	6	133	1.3	1.79	0.16	
S3	South Creek near 294th St E	03/05/2001	6.8	99	6.8	133	1.94	2.76	0.26	
S3	South Creek near 294th St E	04/06/2001	7.8	84	7.5	135	0.89	1.29	0.13	
S3	South Creek near 294th St E	05/08/2001	12.5	92	10.3	137	1.79	2.77	0.31	
S3	South Creek near 294th St E	06/25/2001	13.3	108	12.8	133	2.27	3.32	0.33	

Appendix B - Summary of water level and water quality data for in-stream piezometers and streams within the Muck Creek Watershed, Pierce Co., WA.

Map ID [1]	Location	Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Groundwater Temperature (deg C)	Groundwater Specific Conductance (us/cm@25C)	Ground-Water Depth [2] (feet)	Stream Level [3] (feet)	Vertical Hydraulic Gradient [4] (L/L)	Remarks

[1] The listed Map ID corresponds to the site number shown on Figure 5

[2] The listed value represents the distance to groundwater, in feet, as measured from a consistent reference point at the top of the piezometer

[3] The listed value represents the distance to the creek surface, in feet, as measured from a consistent reference point at the top of the piezometer

[4] Negative values indicate the stream is recharging groundwater while positive values indicate groundwater is discharging to the stream.
Minimum potential gradients (indicated by a ">" value) were calculated when the stream contained water but the piezometer was dry.
An "*" indicates the gradient was calculated based on manometer board measurements of stream stage and groundwater level

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Appendix C

Depth to top of hydrogeologic units for wells used to construct geologic cross sections

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Appendix C - Depth to top of hydrogeologic units for wells used to construct geologic cross sections in the Muck Creek area

Local Number	Well Tag Number	Site Latitude (dms)	Site Longitude (dms)	Land surface altitude (feet)	well depth (feet)	Altitude of top of hydrogeologic unit (feet relative to mean sea level)								
						Qvr	Qvt	Qc1	Cf1	Qc2	Qf2	Qc3	Qf3	Qc4
17N/02E-02E01		465925	1223124	380	139	380	338	-	-	-	-	310	294	268
17N/03E-04A01		465932	1222515	510	209	NP	510	-	-	-	-	380	350	309
17N/03E-04F01		465925	1222604	510	177	NP	510	-	-	-	-	-	463	390
17N/03E-05E01		465927	1222740	420	70	420	408	-	-	-	-	397	395	355
17N/03E-05G01		465927	1222704	435	139	435	419	-	-	-	-	-	339	330
17N/03E-08R01		465809	1222648	435	99	NP	435	-	-	-	-	385	-	-
17N/03E-09D01		465848	1222620	485	203	NP	485	-	-	-	-	406	343	311
17N/03E-16D01		465756	1222624	485	140	NP	485	-	-	-	-	427	-	-
17N/03E-16D02		465753	1222625	485	138	NP	485	-	-	-	-	415	-	-
17N/03E-16E02		465742	1222624	480	86	NP	480	-	-	-	-	405	-	-
17N/03E-20A01		465705	1222633	490	67	NP	490	-	-	-	-	424	-	-
17N/03E-21D02		465702	1222624	480	66	NP	480	-	-	-	-	432	-	-
17N/03E-21M01		465636	1222625	480	80	NP	480	-	-	-	-	406	-	-
17N/03E-37D01		465945	1222851	400	166	400	385	-	-	-	-	350	347	306
17N/04E-04L01		465910	1221825	640	220	640	635	601	561	557	515	512	-	-
17N/04E-04P01		465852	1221839	655	135	655	628	581	576	534	-	-	-	-
17N/04E-04P02		465901	1221839	640	139	640	636	569	555	533	-	-	-	-
17N/04E-05A01		465940	1221908	615	135	615	609	496	-	-	-	-	-	-
17N/04E-16C01		465751	1221828	640	77	640	623	602	-	-	-	-	-	-
17N/04E-16H01		465737	1221754	750	149	NP	750	670	-	-	-	-	-	-
18N/02E-16G01	AEP009	470257	1223310	327	49	327	-	-	-	-	-	-	-	-
18N/02E-21L01	AEP006	470145	1223334	316	44	316	-	-	-	-	-	-	-	-
18N/02E-33J01		470008	1223300	310	55	310	305	-	-	-	-	275	-	-
18N/02E-33J02		470009	1223256	310	106	310	307	-	-	-	-	282	210	202
18N/02E-33K01	AFC087	470003	1223323	315	140	315	292	-	-	-	-	240	195	185
18N/02E-34G02		470018	1223156	335	145	NP	335	-	-	-	-	217	215	205
18N/02E-34G01		470023	1223200	325	26	325	-	-	-	-	-	-	-	-
18N/02E-34J01		470010	1223137	335	120	335	326	-	-	-	-	278	267	238
18N/02E-34R01		465959	1223134	355	107	355	310	-	-	-	-	260	-	-
18N/03E-24B01		470214	1222158	482	79	482	478	-	-	-	-	427	-	-
18N/03E-24N01		470133	1222225	472	120	472	470	-	-	-	-	377	-	-
18N/03E-25M01		470103	1222228	450	92	450	435	394	-	-	-	-	-	-

Appendix C - Depth to top of hydrogeologic units for wells used to construct geologic cross sections in the Muck Creek area

Local Number	Well Tag Number	Site Latitude (dms)	Site Longitude (dms)	Land surface altitude (feet)	well depth (feet)	Altitude of top of hydrogeologic unit (feet relative to mean sea level)								
						Qvr	Qvt	Qc1	Cf1	Qc2	Qf2	Qc3	Qf3	Qc4
18N/03E-25P01	AFC092	470056	1222207	455	83	455	452	-	-	-	-	407	-	-
18N/03E-34E01		470003	1222500	445	164	445	425	-	-	-	-	379	342	308
18N/03E-34J01	ABD831	470001	1222409	462	110	462	402	-	-	-	-	384	-	-
18N/03E-35F01		470010	1222330	460	106	460	454	-	-	-	-	381	-	-
18N/03E-35G01	AFC091	470011	1222318	448	56	448	429	-	-	-	-	395	-	-
18N/03E-36F01		470014	1222210	495	100	NP	-	-	-	495	449	436	-	-
18N/03E-36H01		470017	1222127	670	177	-	670	592	588	502	-	-	-	-
18N/04E-08A01		470400	1221901	430	80	430	385	383	-	-	-	-	-	-
18N/04E-08H01		470347	1221856	512	272	512	494	-	-	-	-	353	344	299
18N/04E-16D01		470309	1221841	525	177	525	505	-	-	-	-	450	409	375
18N/04E-16E01		470247	1221841	515	98?	515	477	-	-	-	-	436	-	-
18N/04E-20A01		470219	1221901	500	66	500	471	-	-	-	-	465	456	449
18N/04E-25Q01		470034	1221417	700	140	NP	700	609	580	-	-	-	-	-
18N/04E-28D01		470125	1221845	755	218	NP	755	650	645	560	-	-	-	-
18N/04E-28M01		470057	1221848	698	114	NP	698	641	630	588	-	-	-	-
18N/04E-31J01		470008	1222022	712	216	NP	712	621	600	518	-	-	-	-
18N/04E-32A01		470032	1221909	750	167	NP	750	695	-	-	-	-	-	-
18N/04E-32C01	AEF394	470030	1221949	725	80	NP	725	703	-	-	-	-	-	-
18N/04E-32J01		465958	1221900	615	170	615	610	525	520	490	463	-	-	-
18N/04E-33E01		470009	1221851	640	251	640	635	594	581	550	480	429	-	-
18N/04E-34B01		470030	1221659	690	142	NP	690	630	-	-	-	-	-	-
18N/04E-34D01		470029	1221740	675	125	NP	675	570	-	-	-	-	-	-
18N/04E-36A01		470029	1221405	690	66	NP	690	-	-	-	-	-	-	-

Appendix D

Drillers lithologic descriptions for wells used in hydrogeologic sections

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Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
17N/02E-02E01	Surface seal	18	18	Richardson	1980
	Brown silty sand and gravel	24	42		
	"Hardpan"	8	50		
	Gray clay and gravel	11	61		
	"Hardpan" and boulders	9	70		
	Brown sand and gravel, seepage	11	81		
	Gray sand and gravel, wet	5	86		
	Red silty tight till, wet	26	112		
	Gray sand and gravel, water-bearing (12 gpm)	7	119		
	Gray sand and gravel/boulders	8	127		
	Brown sand and large gravel	12	139		
17N/03E-04A01	Clay and gravel	6	6	Stanfill	1967
	Cemented gravel and boulders	19	25		
	Sand clay and gravel	50	75		
	Cemented gravel and boulders	20	95		
	Sandy clay	15	110		
	Clay and gravel	20	130		
	Sand and gravel, water-bearing	2	132		
	Cemented gravel	28	160		
	Sandy clay	41	201		
	Sand with some pea gravel	8	209		
17N/03E-04F01	Clay, cobbles, and boulders	17	17	Richardson	1987
	Clay and gravel	23	40		
	Clay, gravel, and boulders	7	47		
	Silty sand	24	71		
	Silty sand and gravel	27	98		
	Silty sand	11	109		
	Silty sand and gravel	11	120		
	Sand and gravel	29	149		
	Sand and gravel, water-bearing	28	177		
17N/03E-05E01	Sandy soil	12	12	Peterson Brothers	1947
	Gravel, clayey	11	23		
	Gravel, water-bearing	2	25		
	Clay and "rock"	40	65		
	Gravel, water-bearing	5	70		
17N/03E-05G01	Topsoil and gravel	2	2	Richardson	1974
	Gravel and boulders	10	12		
	Gravel and boulders, seepage	4	16		
	"Hardpan" and boulders	47	63		
	Gravel, water-bearing	2	65		
	"Hardpan" and boulders	31	96		
	Clay and gravel, water-bearing	5	101		
	Sand, clay, and gravel	4	105		
	Gravel, sand, and boulders, water-bearing	6	111		
	Gravel and boulders, water-bearing	4	115		
	Fine brown sand and some gravel	5	120		
	Cemented sand and gravel	14	134		
	Gravel and sand, water-bearing	5	139		
17N/03E-08R01	Topsoil	4	4	Tacoma Pump	1951
	Clay and gravel	43	47		
	Gravel, cemented with boulder at 50 ft.	3	50		
	Gravel and clay, water-bearing	30	80		
	Gravel and some sand, water-bearing	19	99		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
17N/03E-09D01	Topsoil and gravel	2	2	Richardson	1985
	Gravel and clay	5	7		
	"Hardpan" and boulders	52	59		
	Sand and gravel, water-bearing (25 gpm)	4	63		
	Clay and gravel	5	68		
	"Hardpan" and boulders	11	79		
	Gravel, water-bearing (30 gpm)	5	84		
	Clay and gravel	26	110		
	Sand and gravel, dirty	28	138		
	Sand and gravel, a little water	4	142		
	Clay, sand, and gravel	32	174		
	Sand and gravel, dirty, water-bearing (40 gpm)	7	181		
	"Hardpan" and boulders	13	194		
	Gravel and sand, water-bearing (50 gpm)	9	203		
17N/03E-16D01	Brown sandy till	3	3	Oelke	1990
	Gray till	27	30		
	Blue "broken basalt", water-bearing	10	40		
	Blue "broken basalt" with clay and silt, water-bearing	18	58		
	Clean gravel and sand, coarse	2	60		
	Gravel and sand, coarse	35	95		
	Glacial till, blue basalt	10	105		
	Volcanic rock cinders	35	140		
17N/03E-16D02	Topsoil	3	3	Tacoma Pump	1978
	Gravel, rock, and clay	67	70		
	Rocks, sand, and gravel	50	120		
	Rocks, clay, and gravel	8	128		
	Gravel and sand, water-bearing	10	138		
17N/03E-16E02	Old well - no record	40	40	Tacoma Pump	Unknown
	"Hardpan"	35	75		
	Gravel, hardpacked	10	85		
	Gravel, water-bearing	1	86		
17N/03E-20A01	Topsoil	4	4	Sylte	1951
	Blue clay and boulders	38	42		
	Gravel, cemented and "hardpan"	24	66		
	Pea gravel, some sand	1	67		
17N/03E-21D02	Topsoil	5	5	Tacoma Pump	1956
	"Hardpan"	43	48		
	Cemented gravel	8	56		
	Gravel, water-bearing	10	66		
17N/03E-21M01	Clay and gravel	3	3	Richardson	1957
	Clay and gravel, with large "rocks"	24	27		
	Blue clay	9	36		
	Clay and gravel	11	47		
	"Hardpan"	8	55		
	Clay and gravel	19	74		
	Coarse sand and gravel	1	75		
	No-record	5	80		
17N/03E-37D01	Topsoil and gravel	3	3	Richardson	1970
	Gravel	12	15		
	Blue "hardpan"	35	50		
	Sand and gravel, water-bearing	3	53		
	Yellow clay with sand and gravel	19	72		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
	Yellow clay, sand, and gravel	22	94		
	Sand and gravel, water-bearing (10 gpm)	5	99		
	"Hardpan" with soft streaks	66	165		
	Coarse sand and gravel, water-bearing (80 gpm)	1	166		
17N/04E-04L01	"Hardpan" and brown till, some clay binder	17	17	S-K Pumps	1988
	Gray till and gray clay bound gravel	22	39		
	Loose gray sand and gravel, water-bearing (10-15 gpm)	40	79		
	Brown clay and peat	2	81		
	Gray-blue clay	2	83		
	Sand and gravel with red cinder stone	13	96		
	Brown sand and gravel, water-bearing (28 gpm)	8	104		
	Loose sand and gravel, water-bearing (80 gpm)	2	106		
	Brown sand and gravel and brown sandy clay, water-bearing (50 gpm)	8	114		
	Gray sand and gravel, water-bearing (50 gpm)	4	118		
	Sand and gravel with brown clay, water-bearing (40 gpm)	7	125		
	Brown clay with some small gravel, water-bearing (26 gpm)	3	128		
	Loose sand and gravel	11	139		
	Brown sand and gravel with some brown clay, Water-bearing (80 gpm)	32	171		
	Silty red sand and gravel, water bearing (80 gpm, high iron)	19	190		
	Tan clay	13	203		
	Gravel, water-bearing (100 gpm)	17	220		
17N/04E-04P01	Brown sand and gravel	27	27	Stoican	1986
	Blue gray till, large rock	47	74		
	Gray gravel and clay, water-bearing (5-6 gpm)	5	79		
	Brown clay and gravel	42	121		
	Gravel and clay, water-bearing (45-50 gpm)	14	135		
17N/04E-04P02	Fill dirt	4	4	Stoican	1986
	"Hardpan" and some clay	12	16		
	Gray clay bound gravel with seams of loose medium-to-coarse gravel	55	71		
	Gray sand and gravel, some clay, water-bearing (8-10 gpm)	14	85		
	Yellow-brown clay bound gravel	22	107		
	Brown sand and loose gravel, some clay water-bearing (40-50 gpm)	32	139		
17N/04E-05A01	Peat	6	6	Charlton	1951
	"Hardpan"	113	119		
	Gravel	21	140		
17N/04E-16C01	Brown sandy top soil	5	5	S-K Pumps	1987
	Sand, gravel, and gray clay	12	17		
	Blue-gray till	21	38		
	Gray clay and gravel, water-bearing	39	77		
	Brown clay	*	77		
17N/04E-16H01	Top soil	1	1	Richardson	1979
	Silty sand and gravel	8	9		
	"Hardpan" and boulders	21	30		
	Brown silty sand	4	34		
	Brown silty sand and brown clay, seepage	6	40		
	Brown sand, wet	5	45		
	Sand and gravel with brown clay	35	80		
	Silty sand with small gravel, seepage	20	100		
	Sand with some small gravel, seepage	10	110		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
	Sand with small gravel, trace of brown clay, seepage	10	120		
	Sand, gravel, and gray clay	29	149		
18N/02E-16G01	Gravel with silty sand	10	10	Andrew Drilling	1998
	Gravel and sand	15	25		
	Sandy gravel	5	30		
	Sand with gravel	25	55		
18N/02E-21L01	Gravel and silty gravel with cobbles	2	2	Andrew Drilling	1998
	Gravel with sand, coarse	6	8		
	Sand and gravel with cobbles	22	30		
	Gravel, fine	10	40		
	Sand, fine and gravel	5	45		
18N/02E-33J01	Sand topsoil	5	5	Tacoma Pump	1975
	"Hardpan"	13	18		
	Gravel, little water	2	20		
	Tight sand and gravel	15	35		
	Heavy gravel	4	39		
	Sand and gravel, water-bearing	16	55		
	Brown sand	4	59		
18N/02E-33J02	Sandy loam, some gravel	3	3	Ramlow	1986
	Gray-brown silty sand and gravel	7	10		
	Brown gravel and sand, silt layers	18	28		
	Gray-brown medium sand	11	39		
	Brown medium sand, occasional large gravel	9	48		
	Brown poorly sorted medium sand with gravel	28	76		
	Brown well sorted gravel with sand	14	90		
	Brown gravel, sand, and silt	3	93		
	Brown well sorted gravel with sand	7	100		
	Brown gravel, sand, and silt	8	108		
	Brown sand, gravel, and silt, weathered matrix, tighter with depth, cobble size gravel common, seepage	46	154		
18N/02E-33K01	Topsoil	3	3	Richardson	1993
	Gravel, sand, and silt	7	10		
	Gravel and sand	13	23		
	Cemented sand and gravel	22	45		
	Silt, sand, and gravel	5	50		
	"Rock fractures"	10	60		
	Brown clay, sand, and gravel	15	75		
	Sand and gravel	3	78		
	Compacted sand and gravel	22	100		
	Compacted sand, gravel, and cobbles	20	120		
	Silt, sand, and gravel	10	130		
	Gravel and sand, water bearing	10	140		
18N/02E-34G01	Topsoil	2	2	Sides	Unknown
	Cobbles	24	26		
18N/02E-34G02	Topsoil	1	1	Tacoma Pump	1980
	"Hardpan"	36	37		
	"Hardpan", with seepage	4	41		
	"Hardpan", and rock	77	118		
	Sand, gravel, and clay, water-bearing	2	120		
	"Hardpan"	10	130		
	Sand and gravel, water-bearing	17	147		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
18N/02E-34J01	Topsoil and gravel	1	1	Richardson	1983
	Gravel	8	9		
	"Hardpan"	9	18		
	"Hardpan" and boulders	18	36		
	Clay and gravel	21	57		
	Sand and gravel, water-bearing	11	68		
	"Hardpan"	9	77		
	Gravel and clay, water-bearing	6	83		
	Gravel and clay	6	89		
	Gray clay	4	93		
	Gray clay and gravel	4	97		
	Gravel and sand, water-bearing	12	109		
	Gravel and clay, water-bearing	4	113		
	Gravel, water-bearing	10	123		
18N/02E-34R01	Sand	8	8	Richardson	1976
	Silty sand and gravel	37	45		
	Gravel and clay, water-bearing (2-3 gpm)	50	95		
	Gravel, water-bearing	12	107		
18N/03E-24B01	Gravel fill	4	4	Tacoma Pump	1978
	"Hardpan"	51	55		
	Sand and gravel, water-bearing	25	80		
18N/03E-24N01	Topsoil and rocks	2	2	Tacoma Pump	1984
	"Hardpan"	23	25		
	Sand, gravel, and clay, water-bering	65	90		
	Sand, gravel, and clay	5	95		
	Sand and gravel, water-bearing	25	120		
18N/03E-25M01	Topsoil and gravel	1	1	Richardson	1989
	Gravel and boulders	11	12		
	Boulder	3	15		
	"Hardpan"	8	23		
	Gravel and clay, seepage	2	25		
	Gray sticky clay	3	28		
	Brown sticky clay	5	33		
	Brown "hardpan" and boulders	23	56		
	Reddish brown clay and gravel, water-bearing	7	63		
	Reddish brown clay and gravel	14	77		
	Reddish brown clay and gravel, water-bearing	6	83		
	Gray clay and gravel	4	87		
	Gravel and sand, water-bearing	5	92		
	Gravel and clay	3	95		
18N/03E-25P01	Topsoil	3	3	Tacoma Pump	1980
	"Hardpan"	45	48		
	Sand and Gravel, water-bearing (10-15 gpm)	13	61		
	"Hardpan", seepage	2	63		
	Sand and gravel, water-bearing (20 gpm)	2	65		
	Sand and gravel, wet	6	71		
	Sand and gravel, water-bearing (40 gpm)	12	83		
	Clay, no water	2	85		
18N/03E-34E01	Compact sand and gravel	8	8	Richardson	1985
	Sand, gravel, and boulders	2	10		
	Compact sand and gravel	7	17		
	Sand, gravel, and boulders	1	18		
	Compact sand and gravel	2	20		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
	Dirty silty sand	12	32		
	Moist silty sand	8	40		
	Compact sand and gravel	16	56		
	Compact gravel	10	66		
	Loose gravel	18	84		
	Loose gravel, water-bearing	19	103		
	Brown sand and gravel "hardpan", water-bearing	20	123		
	"Hardpan" with large boulders	14	137		
	Brown sand and gravel	20	157		
	Sand with large gravel, water-bearing	7	164		
18N/03E-34J01	Topsoil	2	2	Dale Well Drilling	1996
	Brown clay rock	33	35		
	Gravel	25	60		
	Rock and clay, gray	18	78		
	Brown clay and rock, water-bearing	32	110		
18N/03E-35F01	Brown rocky clay and gravel	6	6	Harris Well Drilling	1999
	Brown rocky clay	21	27		
	Gray rocky gravel with clay	37	64		
	Brown sandy clay	8	72		
	Light brown rocky clay	7	79		
	Light brown sandy clay and gravel, water-bearing	28	107		
18N/03E-35G01	Topsoil	2	2	Tacoma Pump	1991
	Brown compacted silty sand and gravel, med	5	7		
	Brown compacted silty sand and gravel, course	12	19		
	Brown compacted silty sand and gravel, fine (dry)	15	34		
	Gray compacted sand and "flour", wet	5	39		
	Gray clay and gravel	14	53		
	Gray loose medium sand and gravel, water-bearing	3	56		
	Brown cemented medium sand and gravel, dry	?	>56		
18N/03E-36F01	Gravel and clay	6	6	Richardson	1983
	Gravel and clay, seepage	22	28		
	Gray clay	5	33		
	Sand and gravel	13	46		
	"Hardpan"	13	59		
	Sand and gravel	41	100		
18N/03E-36H01	Topsoil and gravel	2	2	Richardson	1982
	Gravel and boulders	7	9		
	"Hardpan" and boulders	9	18		
	"Hardpan", with seepage	2	20		
	"Hardpan"	58	78		
	Gravel, with a little water	4	82		
	Clay and gravel	30	112		
	Gray sandy clay	26	138		
	Sandy clay and some gravel	19	157		
	Gray sticky clay	7	164		
	Gray sticky clay and gravel, with a little water	4	168		
	Gravel and clay, water-bearing	9	177		
18N/04E-08A01	Compact sand and gravel	4	4	Richardson	1985
	Loose sand and gravel, seepage	10	14		
	Coarse brown sand	2	16		
	Loose sand and gravel, water-bearing (70 gpm)	29	45		
	"Hardpan"	2	47		
	Fine sand	5	52		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
	Sand and gravel, water-bearing (50 gpm)	12	64		
	Fine sand and gravel	4	68		
	Sand and gravel, water-bearing (35 gpm)	6	74		
	Peat	1	75		
	Coarse gravel, water-bearing (80 gpm)	6	81		
18N/04E-08H01	Gravel and boulders	18	18	Richardson	1973
	"Hardpan"	9	27		
	Gravel and boulders	13	40		
	Clay, gravel, and boulders	2	42		
	"Hardpan" and boulders	49	91		
	Yellow clay, sand, and gravel	29	120		
	"Hardpan"	6	126		
	Gravel, seepage	1	127		
	Yellow "hardpan" and boulders	32	159		
	Boulders and gravel	5	164		
	Heaving sand and gravel, water-bearing	1	165		
	Gravel and sand, water-bearing	3	168		
	Cemented sand and gravel	6	174		
	Loose sand and gravel	1	175		
	Compact sand and gravel	6	181		
	Rocks and boulders	1	182		
	Gray cemented sand and gravel	11	193		
	Fine sand and gravel, water-bearing	1	194		
	Brown cemented sand and gravel	10	204		
	Cemented sand and gravel, black rock	5	209		
	Cemented sand and gravel	4	213		
	Dirty sand and gravel with coal and wood	7	220		
	Sand and gravel with some clay, water-bearing	10	230		
	Sand, gravel, boulders, and gray clay	9	239		
	Black basalt, boulders	1	240		
	Fine to coarse sand, gravel, and clay	12	252		
	Gray clay, sand, and gravel	11	263		
	Fine to coarse sand and gravel, water-bearing	5	268		
	Cemented sand, gravel, and boulders	4	272		
18N/04E-16D01	Topsoil	3	3	Tacoma Pump	1970
	Gravel and clay	57	60		
	Packed clay, water-bearing	8	68		
	Hard packed gravel, moist	7	75		
	Sand and gravel, wet	15	90		
	Packed gravel, wet	26	116		
	Rock and clay	3	119		
	Clay and gravel	7	126		
	Sand and clay, wet	4	130		
	Clay with rocks	15	145		
	Clay, sand, and gravel	5	150		
	Packed gravel and sand, water-bearing	20	170		
	Sand and gravel, water-bearing	7	177		
18N/04E-16E01	Soil	2	2	Service Hardware	1952
	"Hardpan" with some large "rocks"	36	38		
	Clay and rocky "hardpan"	22	60		
	Hard packed sand with clay and large "rocks"	16	76		
	Boulders	3	79		
	Hard gravel, water-bearing	7	86		
	Hard gravel	4	90		
	Gravel and large "rocks"	8	98		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
18N/04E-20A01	Sand and gravel, some clay	21	21	S-K Pumps	1988
	Sand and gravel, water-bearing (13 gpm)	8	29		
	Gray till	6	35		
	Sand and gravel with clay seams, water-bearing (30 gpm)	9	44		
	Gray till, some clay	7	51		
	Sand and gravel boulders, water bearing (75 gpm)	15	66		
18N/04E-25Q01	Topsoil and gravel	3	3	Richardson	1983
	Gravel and boulders	4	7		
	"Hardpan"	10	17		
	"Hardpan", seepage	2	19		
	"Hardpan" and boulders	40	59		
	Gravel and clay, water-bearing	3	62		
	"Hardpan" and boulders	29	91		
	Gravel and clay, water-bearing	7	98		
	Gravel and clay	19	117		
	Gravel, clay, and sand, water-bearing	3	120		
	Brown clay	3	123		
	Clay and gravel, with wood	3	126		
	Yellow clay	8	134		
	Cream colored clay	22	156		
	Green sticky clay	47	203		
18N/04E-28D01	Topsoil	2	2	Olympic West	1978
	Brown clay and gravel	12	14		
	Brown sand and gravel	2	16		
	Brown clay and gravel	30	46		
	Brown sand and gravel	32	78		
	Brown clay, sand, and gravel	27	105		
	Sand and gravel, trace of water	5	110		
	Brown clay and sand	7	117		
	Blue clay	78	195		
	Gravel, water-bearing	23	218		
18N/04E-28M01	Brown silty sand and gravel	20	20	Oelke	1986
	Wet sand and coarse gravel	10	30		
	Brown silty sand and gravel	27	57		
	Coarse sand, coarse to medium gravel, water-bearing (17 gpm)	11	68		
	Blue gray silt	42	110		
	Coarse blue gray silty sand with coarse rounded gravel, water-bearing	4	114		
	Blue gray silt	2	116		
18N/04E-31J01	Gravel fill	2	2	Stoican	1985
	Gravel and brown clay	15	17		
	Gray clay	36	53		
	Blue clay	3	56		
	Gray clay with some gravel	35	91		
	Sand and gravel, water-bearing (50 gpm)	21	112		
	Gray silty clay	2	114		
	Gray silty fine sand	34	148		
	Gray clay	28	176		
	Gray medium to fine silty sand with clay seams	18	194		
	Gravel, water-bearing (80 gpm)	20	214		
	Brown clay	2	216		
18N/04E-32A01	Topsoil	2	2	Tacoma Pump	1958
	"Hardpan"	21	23		
	Sandy clay and gravel	32	55		

Appendix D - Drillers lithologic descriptions for wells used in hydrogeologic sections for the Muck Ck. Watershed

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year Drilled
	Dry sand	10	65		
	Sand, water-bearing	59	124		
	Blue clay	33	157		
	Coarse sand	2	159		
	Coarse sand and gravel	8	167		
18N/04E-32C01	Glacial till	5	5	Oelke	1984
	Boulders	13	18		
	Moist brown till with silty sand and gravel	4	22		
	Fractured gravel with sand	8	30		
	Moist coarse sand and gravel	10	40		
	Blue silty clay	17	57		
	Blue silty clay to rounded gravel coarse sand	23	80		
18N/04E-32J01	Clay and clay loam	25	25	Service Hardware	1951
	Sand, water-bearing	1	26		
	Clay with "rocks"	64	90		
	Sand, water-bearing	5	95		
	Packed clay and "rocks"	30	125		
	Rocky clay, water-bearing	27	152		
	Rocky clay	18	170		
18N/04E-33E01	Clay and large "rock"	20	20	Service Hardware	1954
	Hard packed clay and "rock"	12	32		
	Softer clay and "rock"	14	46		
	Clay and "rock" water-bearing	13	59		
	Very hard packed clay and "rock"	16	75		
	Clay	5	80		
	Blue sand and clay	10	90		
	Blue clay and gravel, water-bearing	70	160		
	Brown "hardpan", water-bearing	35	195		
	Coarse gravel	11	206		
	"Rock" and lava	5	211		
	Brown gravel, boulders, and clay, water-bearing	40	251		
18N/04E-34B01	Soil and "hardpan"	60	60	Service Hardware	Unknown
	Gravel and large rock	72	132		
	Brown clay	4	136		
	Boulders	6	142		
18N/04E-34D01	Clay	8	8	Tacoma Pump	1952
	Brown clay and gravel	6	14		
	Blue clay with sand and gravel, water from 22 to 28 feet	14	28		
	"Hardpan", blue, rocks	28	56		
	Sand and clay with gravel, water-bearing	14	70		
	"Hardpan", blue, rocks	6	76		
	Clay and sand	9	85		
	"Hardpan", rocky	20	105		
	Sand, gravel, and clay, water-bearing	12	117		
	Gravel, hardpacked, water-bearing	6	123		
	Gravel, loose, water-bearing	2	125		
18N/04E-36A01	Topsoil	1	1	Roberts	1980
	Red clay and gravel	4	5		
	Cemented gravel	17	22		
	Sandy gray clay	17	39		
	Sandy gray clay and gravel, water-bearing	6	45		
	Packed sand, water-bearing	21	66		

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Appendix E

Daily mean streamflow for Muck Creek at Roy

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Appendix E - Daily mean streamflow for Muck Creek at Roy (Site M4*)

LOCATION: Lat(dms) 470020, Long(dms) 1223230, in SW1/4 NW1/4 Sec. 34, T. 18N., R. 02E., Pierce County, WA.

DRAINAGE AREA: 86.8 square miles

REMARKS: Water-stage recorder, located 150 feet upstream (east) of railroad bridge crossing of Muck Ck, in Roy, right bank
Additional records available for this site (June 1956 - September 1971) under USGS station no. 12090200
Some regulation in lakes above station
Data collected and compiled by CH2MHill, Inc.

Discharge, cubic feet per second, water year October 1999 to September 2000
Daily mean values

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	--	--	--	--	--	--	307	72	30	0.5	0.1	0
2	--	--	--	--	--	--	264	70	29	0.4	0.1	0
3	--	--	--	--	--	--	235	69	28	0.4	0.1	0
4	--	--	--	--	--	--	209	69	26	0.5	0.1	0
5	--	--	--	--	--	--	185	56	25	0.5	0.1	0
6	--	--	--	--	--	--	164	31	24	0.5	0.1	0.1
7	--	--	--	--	--	--	157	34	24	0.4	0.1	0.1
8	--	--	--	--	--	--	144	34	25	0.4	0.1	0.1
9	--	--	--	--	--	--	127	37	24	0.3	0.1	0.1
10	--	--	--	--	--	--	117	45	23	0.3	0.1	0.1
11	--	--	--	--	--	--	108	57	23	0.3	0.1	0.1
12	--	--	--	--	--	--	94	54	24	0.3	0.1	0.1
13	--	--	--	--	--	--	82	52	25	0.3	0.1	0.1
14	--	--	--	--	--	--	86	51	26	0.2	0.1	0.1
15	--	--	--	--	--	--	117	51	22	0.2	0.1	0.1
16	--	--	--	--	--	--	171	50	21	0.2	0.1	0.1
17	--	--	--	--	--	--	178	48	20	0.1	0.1	0.1
18	--	--	--	--	--	--	138	46	19	0.1	0.1	0.1
19	--	--	--	--	--	--	122	45	18	0.1	0.1	0.1
20	--	--	--	--	--	--	97	48	18	0.1	0.1	0.1
21	--	--	--	--	--	--	78	46	11	0.1	0.1	0.1
22	--	--	--	--	--	--	79	43	3.3	0.1	0.1	0.1
23	--	--	--	--	--	--	79	41	3	0.1	0.1	0.1
24	--	--	--	--	--	--	79	40	3	0.1	0.1	0.1
25	--	--	--	--	--	--	78	37	3.3	0.1	0.1	0.1
26	--	--	--	--	--	--	78	34	3	0.1	0.1	0.1
27	--	--	--	--	--	--	76	34	3	0.1	0	0.1
28	--	--	--	--	--	--	78	33	2.8	0.1	0	0.1
29	--	--	--	--	--	438	78	31	1.5	0.1	0	0.1
30	--	--	--	--	--	396	73	31	1.3	0.1	0	0.1
31	--	--	--	--	--	343	--	30	--	0.1	0	--
MAX	--	--	--	--	--	--	307	72	30	0.5	0.1	0.1
MIN	--	--	--	--	--	--	73	30	1.3	0.1	0	0
MEAN	--	--	--	--	--	--	129	46	17	0.23	0.08	0.08

* Shown as Site M4 on Figure 4

Appendix E - Daily mean streamflow for Muck Ck at Roy (Site M4*)--Continued

LOCATION: Lat(dms) 470020, Long(dms) 1223230, in SW1/4 NW1/4 Sec. 34, T. 18N., R. 02E., Pierce County, WA.

DRAINAGE AREA: 86.8 square miles

REMARKS: Water-stage recorder, located 150 feet upstream (east) of railroad bridge crossing of Muck Ck, in Roy, right bank
Additional records available for this site (June 1956 - September 1971) under USGS station no. 12090200
Some regulation in lakes above station
Data collected and compiled by CH2MHill, Inc.

Discharge, cubic feet per second, water year October 2000 to September 2001
Daily mean values

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.1	0.4	3.5	6	18	31	--	--	--	--	--	--
2	0.1	0.4	2.8	5.5	18	32	--	--	--	--	--	--
3	0.1	0.3	2.5	3.5	19	33	--	--	--	--	--	--
4	0.1	0.2	2	3	20	34	--	--	--	--	--	--
5	0.1	0.3	1.8	3.8	23	34	--	--	--	--	--	--
6	0.1	0.3	1.5	9.9	33	31	--	--	--	--	--	--
7	0.1	0.4	1.3	12	30	--	--	--	--	--	--	--
8	0.1	0.4	1.3	8.5	26	--	--	--	--	--	--	--
9	0.1	1.3	1	6	25	--	--	--	--	--	--	--
10	0.1	2.3	1	3.5	25	--	--	--	--	--	--	--
11	0.1	3.3	1	3.5	25	--	--	--	--	--	--	--
12	0.1	2.5	0.75	3.5	26	--	--	--	--	--	--	--
13	0.1	1.3	0.75	3.3	25	--	--	--	--	--	--	--
14	0.1	0.5	0.75	3.5	25	--	--	--	--	--	--	--
15	0.1	0.5	0.75	5.5	27	--	--	--	--	--	--	--
16	0.1	0.4	1.3	7.5	28	--	--	--	--	--	--	--
17	0.2	0.3	2.8	7.5	31	--	--	--	--	--	--	--
18	0.4	0.3	7	8	34	--	--	--	--	--	--	--
19	1	0.2	10	8.9	37	--	--	--	--	--	--	--
20	1.3	0.2	7.5	9.9	36	--	--	--	--	--	--	--
21	3	0.2	5.5	11	34	--	--	--	--	--	--	--
22	2.3	0.2	4	12	34	--	--	--	--	--	--	--
23	2.5	0.2	3.8	13	34	--	--	--	--	--	--	--
24	2.5	0.3	3.8	14	34	--	--	--	--	--	--	--
25	0.75	0.3	5.5	14	34	--	--	--	--	--	--	--
26	0.5	0.5	7	14	33	--	--	--	--	--	--	--
27	0.4	1.5	5.5	14	33	--	--	--	--	--	--	--
28	0.3	4	4	14	32	--	--	--	--	--	--	--
29	0.5	7	2.8	16	--	--	--	--	--	--	--	--
30	0.4	6.5	3	16	--	--	--	--	--	--	--	--
31	0.4	--	3.3	17	--	--	--	--	--	--	--	--
MAX	3	7	10	17	37	--	--	--	--	--	--	--
MIN	0.1	0.2	0.75	3	18	--	--	--	--	--	--	--
MEAN	0.26	1.2	3.2	9	29	--	--	--	--	--	--	--

* Shown as Site M4 on Figure 4

Appendix F

Daily mean streamflow for Muck Creek near Loveland

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Appendix F - Daily mean streamflow for Muck Creek near Loveland (Site M22*)

LOCATION: Lat(dms) 470054, Long(dms) 1222513, in NE1/4 SE1/4 Sec. 28, T. 18N., R. 03E., Pierce County, WA.

DRAINAGE AREA: 16.9 square miles

REMARKS: Water-stage recorder, located 500 feet downstream (west of 8th Avenue E. Bridge, right bank)
no regulation above gage
Data collected and compiled by CH2MHill, Inc.

Discharge, cubic feet per second, water year October 1999 to September 2000
Daily mean values

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	--	--	--	--	--	--	16	11	15	5.3	2.6	2.2
2	--	--	--	--	--	--	15	13	13	5.0	2.6	2.3
3	--	--	--	--	--	--	14	15	10	6.3	2.6	2.4
4	--	--	--	--	--	--	14	16	9.6	5.6	2.6	2.4
5	--	--	--	--	--	--	13	17	7.9	5.1	2.5	2.4
6	--	--	--	--	--	--	14	19	8.8	4.7	2.6	2.6
7	--	--	--	--	--	--	13	15	9.6	5.0	2.6	2.6
8	--	--	--	--	--	--	12	14	12	4.7	2.6	2.7
9	--	--	--	--	--	--	11	16	10	4.6	2.6	2.8
10	--	--	--	--	--	--	11	26	14	4.3	2.6	2.8
11	--	--	--	--	--	--	10	22	14	3.8	2.6	2.8
12	--	--	--	--	--	--	10	21	21	4.6	2.6	2.7
13	--	--	--	--	--	--	12	19	18	4.4	2.6	2.7
14	--	--	--	--	--	--	23	18	15	4.2	2.6	2.7
15	--	--	--	--	--	--	44	17	14	4.3	2.6	2.8
16	--	--	--	--	--	--	47	16	13	4.2	2.5	2.9
17	--	--	--	--	--	--	44	15	11	4.0	2.6	2.9
18	--	--	--	--	--	--	43	15	10	3.8	2.0	2.9
19	--	--	--	--	--	--	38	21	9.9	3.5	2.2	3.0
20	--	--	--	--	--	--	37	19	9.4	3.4	2.1	3.0
21	--	--	--	--	--	--	13	19	8.8	3.4	2.0	3.1
22	--	--	--	--	--	--	14	17	8.6	3.3	2.0	3.0
23	--	--	--	--	--	--	13	15	8.3	3.3	2.0	3.0
24	--	--	--	--	--	--	13	14	7.7	3.2	2.0	3.0
25	--	--	--	--	--	--	13	14	7.7	3.1	2.0	3.0
26	--	--	--	--	--	--	13	15	7.7	3.1	2.0	3.0
27	--	--	--	--	--	--	12	15	6.4	3.0	2.0	3.0
28	--	--	--	--	--	24	14	14	6.4	2.9	2.0	3.0
29	--	--	--	--	--	23	13	15	5.7	2.8	2.0	3.1
30	--	--	--	--	--	20	12	16	5.6	2.6	2.2	3.3
31	--	--	--	--	--	18	--	16	--	2.7	2.2	--
MAX	--	--	--	--	--	--	47	26	21	6.3	2.6	3.3
MIN	--	--	--	--	--	--	10	11	5.6	2.6	2.0	2.2
MEAN	--	--	--	--	--	--	19	17	11	4.0	2.3	2.8

* Shown as Site M22 on Figure 4

Appendix F - Daily mean streamflow for Muck Ck near Loveland (Site M22*)--Continued

LOCATION: Lat(dms) 470054, Long(dms) 1222513, in NE1/4 SE1/4 Sec. 28, T. 18N., R. 03E., Pierce County, WA.

DRAINAGE AREA: 16.9 square miles

REMARKS: Water-stage recorder, located 500 feet downstream (west of 8th Avenue E. Bridge, right bank)
no regulation above gage
Data collected and compiled by CH2MHill, Inc.

Discharge, cubic feet per second, water year October 2000 to September 2001
Daily mean values

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.6	3.5	5.6	8.3	6.4	5.9	--	--	--	--	--	--
2	3.4	3.5	5.9	7.9	6.6	6.8	--	--	--	--	--	--
3	3.3	3.5	6.1	7.9	6.8	6.4	--	--	--	--	--	--
4	3.3	3.6	5.9	9.4	9.4	6.1	--	--	--	--	--	--
5	3.3	3.6	5.7	9.6	9.6	6.3	--	--	--	--	--	--
6	3.3	3.7	5.9	9.9	9.1	--	--	--	--	--	--	--
7	3.3	3.8	5.9	9.6	8.6	--	--	--	--	--	--	--
8	3.2	4.3	5.7	9.6	8.8	--	--	--	--	--	--	--
9	3.5	4.6	5.9	9.6	9.1	--	--	--	--	--	--	--
10	3.8	4.3	5.9	9.1	8.1	--	--	--	--	--	--	--
11	3.8	4.2	5.7	8.8	8.1	--	--	--	--	--	--	--
12	3.6	4.2	5.6	8.6	7.2	--	--	--	--	--	--	--
13	3.6	4.2	5.7	8.6	7.0	--	--	--	--	--	--	--
14	3.5	4.2	5.6	9.4	6.8	--	--	--	--	--	--	--
15	3.5	4.1	6.4	8.6	6.8	--	--	--	--	--	--	--
16	3.6	4.2	6.4	8.1	8.1	--	--	--	--	--	--	--
17	4.1	4.2	7.4	7.9	9.4	--	--	--	--	--	--	--
18	3.8	4.2	7.2	8.1	8.8	--	--	--	--	--	--	--
19	3.7	4.3	7.2	8.1	7.9	--	--	--	--	--	--	--
20	4.2	4.2	7.0	7.9	7.2	--	--	--	--	--	--	--
21	4.3	4.1	7.2	8.3	7.0	--	--	--	--	--	--	--
22	4.1	4.3	7.2	8.6	7.0	--	--	--	--	--	--	--
23	4.1	4.6	7.7	7.9	6.8	--	--	--	--	--	--	--
24	4.0	5.1	8.1	7.7	6.6	--	--	--	--	--	--	--
25	4.0	5.0	7.7	7.4	6.3	--	--	--	--	--	--	--
26	4.0	5.4	7.4	7.0	6.1	--	--	--	--	--	--	--
27	3.7	5.6	7.9	6.6	5.7	--	--	--	--	--	--	--
28	4.0	5.7	7.7	6.4	5.6	--	--	--	--	--	--	--
29	4.1	5.7	7.4	6.6	--	--	--	--	--	--	--	--
30	3.7	5.6	8.6	6.4	--	--	--	--	--	--	--	--
31	3.6	--	8.6	6.8	--	--	--	--	--	--	--	--
MAX	4.3	5.7	8.6	9.9	9.6	--	--	--	--	--	--	--
MIN	3.2	3.5	5.6	6.4	5.6	--	--	--	--	--	--	--
MEAN	3.7	4.4	6.7	8.2	7.5	--	--	--	--	--	--	--

* Shown as Site M22 on Figure 4

Appendix G

Miscellaneous streamflow and water quality data

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Appendix G - Miscellaneous streamflow and water quality data for the Muck Creek watershed

Map ID[1]	Station description and location	Sample Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Measured Streamflow (ft3/sec)	Data Source[2]	Remarks
M1	**Muck Ck at bridge 200 feet upstream of mouth**	08/08/1975	-	-	8.06	U	
	Location: T18N/R01E/36 SE,SW	09/12/1975	-	-	4.72	U	
		10/21/1975	-	-	2.40	U	
		11/17/1975	-	-	1.45	U	
		12/11/1975	-	-	362.00	U	
		01/14/1976	-	-	344.00	U	
		02/13/1976	-	-	138.00	U	
		03/24/1976	-	-	145.00	U	
		04/23/1976	-	-	116.00	U	
		05/14/1976	-	-	61.50	U	
		06/15/1976	-	-	24.90	U	
		07/09/1976	-	-	15.00	U	
		08/09/1976	-	-	10.20	U	
		09/10/1976	-	-	6.91	U	
		10/13/1976	-	-	5.19	U	
		11/11/1976	-	-	2.32	U	
		01/11/1977	-	-	0.61	U	
		03/18/1977	-	-	30.50	U	
		05/12/1977	-	-	13.80	U	
		06/09/1977	-	-	15.10	U	
		07/08/1977	-	-	9.84	U	
		08/08/1977	-	-	7.12	U	
		08/31/2000	11.7	98	6.93		
		09/20/2000	10.3	-	5.35		
M2	**Muck Ck at military bridge 0.5 miles W of Roy**	10/28/1960	-	-	8.43	U	
	Location: T18N/R02E-33 SW,NE	10/20/1961	-	-	2.48	U	
M3	**Halverson marsh outlet, trib to Muck Ck**	10/28/1960	-	-	4.01	U	
	Location: T18N/R02E-33 NE,NE	10/20/1961	-	-	2.14	U	
M4	**Muck Ck at USGS gage 12090200**	07/05/1949	-	-	2.99	U	
	Location: T18N/R02E-34 SW,NW	07/20/1949	-	-	0.22	U	
		08/02/1949	-	-	0.13	U	
		08/18/1949	-	-	0.04	U	
		09/06/1949	-	-	0.00	U	
		10/28/1960	-	-	4.01	U	
		08/08/1975	-	-	0.90	U	
		10/21/1975	-	-	1.30	U	
		11/17/1975	-	-	24.60	U	
		07/09/1976	-	-	4.97	U	
		08/09/1976	-	-	2.26	U	
		09/10/1976	-	-	3.32	U	
		10/13/1976	-	-	0.65	U	
		11/11/1976	-	-	0.63	U	
		01/11/1977	-	-	1.51	U	
		03/18/1977	-	-	34.00	U	
		05/12/1977	-	-	6.78	U	
		06/09/1977	-	-	13.30	U	
		07/08/1977	-	-	1.43	U	
		08/08/1977	-	-	0.00	U	
		09/02/1999	-	-	2.40		
		06/06/2000	-	-	21.80		
		06/07/2000	-	-	23.00		

Appendix G - Miscellaneous streamflow and water quality data for the Muck Creek watershed

Map ID[1]	Station description and location	Sample Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Measured Streamflow (ft3/sec)	Data Source[2]	Remarks
		08/17/2000	-	-	0.00		Creek Dry
		08/31/2000	-	-	0.00		Creek Dry
		09/21/2000	-	-	0.00		Creek Dry
		02/09/2001	-	-	25.80		
M5	**Muck Ck at bridge 200 ft below Chambers Lk**	06/19/1947	-	-	0.64	U	
	Location: T18N/R02E-27 SW,SE	06/15/1960	-	-	31.60	U	
		10/24/1960	-	-	3.76	U	
		10/20/1961	-	-	1.05	U	
		12/17/1965	-	-	2.54	U	
		07/15/1966	-	-	11.00	U	
		01/08/1968	-	-	10.50	U	
		07/25/1969	-	-	3.31	U	
		08/07/1970	-	-	2.22	U	
		09/21/1999	19.5	88	0.71		Poor section
		06/06/2000	-	-	16.70		
M6	**Muck Ck upstream from Chambers Lk**	06/15/1960	-	-	61.20	U	
	Location: T18N/R02E-23 SW,SE	10/24/1960	-	-	7.64	U	
		10/20/1961	-	-	3.67	U	
		12/17/1965	-	-	7.08	U	
		07/15/1966	-	-	14.10	U	
		01/08/1968	-	-	37.40	U	
		07/25/1969	-	-	13.70	U	
		08/07/1970	-	-	9.52	U	
M7	**Muck Ck 300 ft downstream from Shaver Lk**	10/24/1960	-	-	4.53	U	
	Location: T18N/R02E-23 NW,SE	10/20/1961	-	-	2.23	U	
		08/07/1970	-	-	1.01	U	
M8	**Johnson Lk Outlet Ck 1400 ft below E gate Rd**	10/24/1960	-	-	3.85	U	
	Location: T18N/R02E-24 NW,NW		-	-			
M9	**Johnson Lk Outlet Ck 150 ft above E gate Rd**	06/19/1957	-	-	5.70	U	
	Location: T18N/R02E-13 SW,SW	09/05/1957	-	-	0.67	U	
M10	**Muck Ck above Johnson Lk outlet**	10/24/1960	-	-	1.26	U	
	Location: T18N/R02E-24 SE,NW	10/20/1961	-	-	3.10	U	
M11	**Muck Ck at State Hwy 507**	08/18/1949	-	-	0.00	U	
	Location: T18N/R02E-24 SW,NE	06/19/1957	-	-	3.92	U	
		09/05/1957	-	-	1.48	U	
		08/24/1999	-	-	0.00		Creek Dry
		09/02/1999	-	-	0.00		Creek Dry
		12/14/1999	-	-	0.00		Creek Dry
		04/26/2000	-	-	0.00		Creek Dry
		05/04/2000	-	-	0.00		Creek Dry
		05/24/2000	-	-	0.00		Creek Dry
		06/06/2000	-	-	0.00		Creek Dry
		06/30/2000	-	-	0.00		Creek Dry
		07/13/2000	-	-	0.00		Creek Dry
		07/27/2000	-	-	0.00		Creek Dry
		08/17/2000	-	-	0.00		Creek Dry
		08/31/2000	-	-	0.00		Creek Dry

Appendix G - Miscellaneous streamflow and water quality data for the Muck Creek watershed

Map ID[1]	Station description and location	Sample Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Measured Streamflow (ft3/sec)	Data Source[2]	Remarks
		09/19/2000	-	-	0.00		Creek Dry
		10/25/2000	-	-	0.00		Creek Dry
		11/28/2000	-	-	0.00		Creek Dry
		12/22/2000	-	-	0.00		Creek Dry
		01/10/2001	-	-	0.00		Creek Dry
		02/07/2001	-	-	0.00		Creek Dry
		03/05/2001	-	-	0.00		Creek Dry
		04/06/2001	-	-	0.00		Creek Dry
		05/08/2001	-	-	0.00		Creek Dry
		06/25/2001	-	-	0.00		Creek Dry
M12	**Muck Ck at piezometer HEC-12**	08/31/2000	-	-	0.00		Creek Dry
	Location: T18N/R02E-24 NW,SE	09/19/2000	-	-	0.00		Creek Dry
		10/25/2000	-	-	0.00		Creek Dry
		11/28/2000	-	-	0.00		Creek Dry
		12/22/2000	-	-	0.00		Creek Dry
		01/10/2001	-	-	0.00		Creek Dry
		02/07/2001	-	-	0.00		Creek Dry
		03/05/2001	-	-	0.00		Creek Dry
		05/08/2001	-	-	0.00		Creek Dry
		06/25/2001	-	-	0.00		Creek Dry
M13	**Muck Ck at piezometer ECY-3**	06/06/2000	-	-	0.00		Creek Dry
	Location: T18N/R03E-19 NW,SW	06/30/2000	-	-	0.00		Creek Dry
		07/27/2000	-	-	0.00		Creek Dry
		08/17/2000	-	-	0.00		Creek Dry
		08/31/2000	-	-	0.00		Creek Dry
		09/19/2000	-	-	0.00		Creek Dry
		10/25/2000	-	-	0.00		Creek Dry
		11/28/2000	-	-	0.00		Creek Dry
		12/22/2000	-	-	0.00		Creek Dry
		01/10/2001	-	-	0.00		Creek Dry
		03/05/2001	-	-	0.00		Creek Dry
		06/25/2001	-	-	0.00		Creek Dry
M14	**Muck Ck at piezometer ECY-4**	07/27/2000	-	-	0.00		Creek Dry
	Location: T18N/R03E-37 NW,NE	08/17/2000	-	-	0.00		Creek Dry
		08/31/2000	-	-	0.00		Creek Dry
		09/19/2000	-	-	0.00		Creek Dry
		10/25/2000	-	-	0.00		Creek Dry
		11/28/2000	-	-	0.00		Creek Dry
		02/09/2001	-	-	23.00		
M16	**Muck Ck at piezometer HEC-7**	08/17/2000	-	-	1.56		
	Location: T18N/R03E-38 NE,NW		-	-			
M17	**Muck Ck at piezometer ECY-5**	02/09/2001	-	-	28.35		
	Location: T18N/R03E-38 NW,NE		-	-			
M19	**Muck Ck near 8th Ave S**	06/06/2000	-	-	6.99		
	Location: T18N/R03E-38 SE,SE	07/13/2000	-	-	2.04		
		07/27/2000	-	-	2.15		
		08/17/2000	-	-	1.76		
		09/19/2000	-	-	1.45		

Appendix G - Miscellaneous streamflow and water quality data for the Muck Creek watershed

Map ID[1]	Station description and location	Sample Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Measured Streamflow (ft3/sec)	Data Source[2]	Remarks
M22	**Muck Ck at 8th Ave E**	06/06/2000	-	-	7.80		
	Location: T18N/R03E-41 NW,NW	07/13/2000	-	-	4.98		
		08/17/2000	-	-	2.36		
		09/19/2000	-	-	2.27		
		02/09/2001	-	-	7.60		
M23	**Muck Ck at Weiler Rd**	09/02/1999	-	-	3.80		
	Location: T18N/R03E-36 NE,NW	09/21/1999	-	-	3.50		
		06/06/2000	-	-	7.45		
		07/13/2000	-	-	4.95		
		08/17/2000	-	-	3.05		
		09/19/2000	-	-	3.89		
M24	**Muck Ck at 70th Ave E**	09/02/1999	-	-	2.50		
	Location: T18N/R04E-30 SE,NE	06/06/2000	-	-	5.31		
		07/13/2000	-	-	3.51		
		08/17/2000	-	-	2.28		
		09/19/2000	-	-	2.53		
L1	**Lacamas Ck at State Hwy 507**	06/06/2000	-	-	2.46		4.25 staff gage
	Location: T18N/R02E-34 SE,NE	06/07/2000	-	-	2.88		4.27 staff gage
		07/13/2000	17.2	145	0.90		4.12 staff gage
		07/26/2000	-	-	0.52*		4.06 staff gage
		08/17/2000	12.8	189	0.37		4.0 staff gage
		08/31/2000	-	-	0.37*		4.0 staff gage
		09/19/2000	-	-	0.44		4.04 staff gage
		09/21/2000	13.4	143	0.45*		4.04 staff gage
		10/25/2000	8.2	154	2.8*		4.27 staff gage
		11/28/2000	1.9	168	12*		4.60 staff gage
		12/22/2000	4.1	186	7.6*		4.47 staff gage
		01/10/2001	3.7	187	9.2*		4.52 staff gage
		02/07/2001	1.9	175	12*		4.6 staff gage
		02/09/2001	-	-	10.56		4.56 staff gage
		03/05/2001	5.4	174	6.7*		4.44 staff gage
		04/06/2001	7.3	153	10.9*		4.57 staff gage
		05/08/2001	11.0	151	5.2*		4.38 staff gage
		06/25/2001	12.2	159	1.2*		4.15 staff gage
L2	**Lacamas Ck at 280th St**	07/05/1949	-	-	1.24	U	
	Location: T18N/R02E-34 NE,SE	07/20/1949	-	-	1.06	U	
		06/19/1957	-	-	2.66	U	
		09/05/1957	-	-	0.63	U	
		09/01/1967	-	-	0.38	U	
		08/08/1975	-	-	1.14	U	
		06/18/1986	-	-	0.73	E	
		07/21/1986	-	-	0.00	E	
		08/19/1986	-	-	0.00	E	
		09/10/1986	-	-	0.00	E	
		10/02/1986	-	-	0.00	E	
		04/12/1987	-	-	4.10	E	
		04/28/1987	-	-	2.40	E	
		06/04/1987	-	-	0.02	E	
		06/24/1987	-	-	0.00	E	

Appendix G - Miscellaneous streamflow and water quality data for the Muck Creek watershed

Map ID[1]	Station description and location	Sample Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Measured Streamflow (ft3/sec)	Data Source[2]	Remarks
		07/21/1987	-	-	1.50	E	
		08/24/1987	-	-	0.78	E	
		09/24/1987	-	-	0.73	E	
		03/30/1988	-	-	38.00	E	
		05/03/1988	-	-	13.00	E	
		05/25/1988	-	-	7.10	E	
		07/13/1988	-	-	1.20	E	
		07/28/1988	-	-	1.10	E	
		01/03/1989	-	-	21.00	E	
		02/13/1989	-	-	7.90	E	
		04/03/1989	-	-	54.00	E	
		06/02/1989	-	-	3.80	E	
		06/30/1989	-	-	1.40	E	
		07/17/1989	-	-	0.96	E	
		08/17/1989	-	-	0.19	E	
		08/31/1989	-	-	0.62	E	
		09/14/1989	-	-	0.55	E	
		11/16/1989	-	-	4.00	E	
		08/24/1999	18.2	150			
L3	**Lacamas Ck at 56th Ave S**	08/02/1949	-	-	1.03	U	
	Location: T18N/R02E-35 NE,SE	08/18/1949	-	-	0.96	U	
		09/06/1949	-	-	0.94	U	
		10/03/1949	-	-	1.15	U	
		06/07/2000	-	-	2.43		
		08/24/1999	19.0	158			
		09/20/2000	14.5	-	0.24		
L4	**Lacamas Ck at 40th Ave S**	06/07/2000	-	-	2.44		
	Location: T17N/R02E-01 NE,NE	08/24/1999	17.9	170			
		09/20/2000	15.2	-	0.85		
L5	**Lacamas Ck at 8th Ave S**	06/07/2000	-	-	1.31		
	Location: T17N/R03E-09 SW,SW	07/13/2000	-	-	0.98		
		07/27/2000	-	-	0.87		
		09/20/2000	-	-	0.90		
S1	**South Ck at 8th Ave E**	07/05/1949	-	-	0.03	U	
	Location: T18N/R03E-33 NE,NE	08/02/1949	-	-	0.00	U	
		08/24/1999	-	-	0.00		Creek Dry
		09/02/1999	-	-	0.00		Creek Dry
		06/07/2000	-	-	1.71		
		06/30/2000	-	-	0.00		Creek dry
		07/13/2000	-	-	0.00		Creek dry
		07/27/2000	-	-	0.00		Creek dry
		08/17/2000	-	-	0.00		Creek dry
		08/31/2000	-	-	0.00		Creek dry
		09/19/2000	-	-	0.00		Creek dry
		10/25/2000	-	-	0.00		Creek dry
S2	**South Ck at 28th Ave E**	08/24/1999	-	-	0.00		Pools, no flow
	Location: T18N/R03E-35 SE,NW	06/07/2000	14.3	105	4.15		
		07/26/2000	18.2	121			
		08/30/2000	-	-	0.00		Creek Dry

Appendix G - Miscellaneous streamflow and water quality data for the Muck Creek watershed

Map ID[1]	Station description and location	Sample Date	Stream Temperature (deg C)	Stream Specific Conductance (us/cm@25C)	Measured Streamflow (ft3/sec)	Data Source[2]	Remarks
		09/21/2000	-	-	0.00		Creek Dry
		10/25/2000	8.0	129			
		11/28/2000	3.4	104			
S3	**South Ck near 294th St E**	06/07/2000	-	-	4.71		
	Location: T17N/R03E-02 SE,NE	07/13/2000	-	-	1.07		
		07/27/2000	-	-	0.71		
		08/17/2000	-	-	0.26		
		09/20/2000	-	-	0.25		
S4	**South Ck at 304th St near 48th Ave**	09/02/1999	11.7	127	0.00		Pools, no flow
	Location: T17N/R03E-12 NE,NW						
S5	**South Ck at 320th St (W of Hwy 7)**	06/07/2000	13.7	96	2.96		
	Location: T17N/R03E-12 SW,SE	09/20/2000	15.8	-	< 0.1		Flow estimated
S6	**South Ck at State Hwy 7**	08/24/1999	-	-	0.00		Creek Dry
	Location: T17N/R03E-24 NE,NE	09/20/2000	-	-	0.00		Creek Dry
S7	**South Ck at 320th St (E of Hwy 7)**	08/24/1999	-	-	0.00		Pools, no flow
	Location: T17N/04E-17 NW,NW						
S8	**South Ck at Lebor Devore Rd**	08/24/1999	-	-	0.00		Pools, no flow
	Location: T17N/R04E-08 SE,SE						
S9	**South Ck at Webster Rd**	08/24/1999	-	-	0.00		Pools, no flow
	Location: T17N/R04E-09 SW,SE						
S10	**South Ck at State Hwy 161**	08/24/1999	-	-	0.00		Pools, no flow
	Location: T17N/R04E-10 SW,NW						
S11	**South Ck at 304th St**	08/24/1999	17.4	91	0.00		Pools, no flow
	Location: T17N/R04E-03 SE,SW	09/02/1999	14.1	94	0.00		Pools, no flow
S12	**South Ck at 118th Ave E**	08/24/1999	-	-	0.00		Creek Dry
	Location: T17N/R04E-02 NW,SW						
S13	**South Ck at 288th St near 126th Ave E**	09/02/1999	12.2	138	0.00		Pools, no flow
	Location: T17N/04E-02 NE,NW						
S14	**South Ck at 264th St E**	08/24/1999	-	-	0.00		Creek Dry
	Location: T18N/R04E-26 SE,NW						
S15	**South Ck at 288th St E**	08/24/1999	-	-	0.00		Pools, no flow
	Location: T18N/R04E-33 SE,SW						

[1] Map ID number corresponds with site numbers shown on Figure 4

[2] Data source: E--Eylar, etal, 1990, U--Williams and Riis, 1989.

* Flow estimated from staff gage rating curve using the following regression equation:

$y = 31.193x^2 - 248.8x + 496.48$ where $R^2 = 1$

where "y" is estimated streamflow (in cubic feet per second) and "x" is the known stage height from the staff gage (in feet)

Appendix H

Summary of groundwater levels, temperature, and specific conductance for monthly observation wells within the Muck Creek watershed

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Appendix H - Summary of groundwater levels, temperature, and specific conductance for monthly observation wells within the Muck Creek watershed

Local Number	Well Tag Number	Sample Date	Temperature (Deg C)	Specific Conductance (us/cm@25C)	Water Level (feet) [1]	Water Level Status [2]	Water Level Method [3]
18N/03E-34J01	ABD831	04-10-1996	-	-	34.65		R
		05-04-2000	-	-	38.6		T
		05-25-2000	-	-	39.85		T
		06-28-2000	-	-	43.22		T
		07-26-2000	-	-	46.75		T
		08-30-2000	-	-	50.37		T
		09-28-2000	-	-	51.41		T
		10-26-2000	-	-	52.09		T
		11-29-2000	-	-	51.81		T
		01-09-2001	-	-	46.93		T
		02-08-2001	-	-	45.79		T
		03-06-2001	-	-	45.09		T
		04-09-2001	-	-	43.18		T
		05-09-2001	-	-	41.5		T
17N/04E-07C01	AFC085	09-08-1976	-	-	51.6		R
		05-18-2000	-	-	35.3	R	T
		06-28-2000	-	-	33.91		T
		07-26-2000	-	-	36.71		T
		08-30-2000	-	-	39.48		T
		09-28-2000	-	-	38.5		T
		10-26-2000	-	-	39.42	R	T
		11-29-2000	-	-	38.14		T
		01-09-2001	-	-	34.93		T
		02-08-2001	-	-	33.97		T
		03-06-2001	-	-	36.84		T
		04-09-2001	-	-	40.7	R	T
		05-09-2001	-	-	40.92		T
18N/02E-34N01	AFC086	02-04-2000	-	-	4.15		T
		02-22-2000	-	-	4.05		T
		03-23-2000	-	-	3.72		T
		04-18-2000	-	-	4.51		T
		05-24-2000	9.4	119	5.33		T
		06-28-2000	10.5	118	6.91		T
		07-26-2000	11.7	134	7.9		T
		08-17-2000	12.3	129	8.9		T
		08-30-2000	12.4	124	9.18		T
		09-28-2000	12.5	126	9.95		T
		10-26-2000	12.3	128	10.23		T
		11-29-2000	11	134	10.19		T
		01-09-2001	10	164	7.58		T
		02-08-2001	9.2	176	7.25		T
		03-06-2001	8.5	172	6.71		T
		04-09-2001	8.2	146	6.53		T

Appendix H - Summary of groundwater levels, temperature, and specific conductance for monthly observation wells within the Muck Creek watershed

Local Number	Well Tag Number	Sample Date	Temperature (Deg C)	Specific Conductance (us/cm@25C)	Water Level (feet) [1]	Water Level Status [2]	Water Level Method [3]
		05-09-2001	8.7	134	5.86		T
		06-25-2001	10.8	132	7.24		T
18N/02E-33K01	AFC087	10-20-1993	-	-	92.5		R
		04-18-2000	-	-	89.96		T
		05-25-2000	-	-	90.3		T
		06-28-2000	-	135	91.4		T
		07-26-2000	10.9	140	92.19	R	T
		08-30-2000	11.4	139	93.26	R	T
		09-28-2000	10.6	150	93.97	R	T
		11-29-2000	9.9	149	94.4	R	T
		01-09-2001	9.5	150	94.26		T
		02-08-2001	8.4	158	94.24	R	T
		03-06-2001	9.7	152	93.81		T
		04-09-2001	9.9	160	93.4		T
		05-09-2001	10.5	157	92.55		T
17N/03E-01R01	AFC088	05-20-1989	-	-	59		R
		04-18-2000	-	-	57.2		T
		05-25-2000	-	-	57.95		T
		06-28-2000	-	-	60.03		T
		07-26-2000	-	-	63.3		T
		08-30-2000	-	-	65.3		T
		09-28-2000	-	-	63.47		T
		10-26-2000	-	-	62.47		T
		11-29-2000	-	-	61.85		T
		01-09-2001	-	-	60.48		T
		02-08-2001	-	-	59.89		T
		03-06-2001	-	-	60.13		T
		04-09-2001	-	-	64.81		T
		05-09-2001	-	-	65.63		T
		06-25-2001	-	-	67.25		T
17N/03E-16D03	AFC089	07-14-1978	-	-	19.55		R
		04-18-2000	-	-	24.93		T
		05-25-2000	-	-	26.09		T
		06-28-2000	-	275	35.46		T
		06-30-2000	-	-	35.86		T
		07-26-2000	-	276	41.34		T
		08-30-2000	-	276	34.29		T
		09-28-2000	-	276	31.8		T
		10-26-2000	-	277	31.52		T
		11-29-2000	-	273	30.96		T
		01-09-2001	-	268	29.36		T
		02-08-2001	-	275	28.65		T
		03-06-2001	-	284	28.02		T

Appendix H - Summary of groundwater levels, temperature, and specific conductance for monthly observation wells within the Muck Creek watershed

Local Number	Well Tag Number	Sample Date	Temperature (Deg C)	Specific Conductance (us/cm@25C)	Water Level (feet) [1]	Water Level Status [2]	Water Level Method [3]
		04-09-2001	-	-	28.1		T
		05-09-2001	-	-	27.65		T
		06-25-2001	-	-	30.3		T
18N/03E-26P01	AFC090	06-22-1989	-	-	37.3		R
		05-25-2000	-	-	31.03		T
		06-28-2000	-	121	34.62		T
		07-26-2000	11	123	37.03		T
		08-30-2000	10.8	122	38.56		T
		09-28-2000	10.6	129	38.52		T
		10-26-2000	10.5	123	38.07		T
		11-29-2000	10.5	123	35.61		T
		01-09-2001	10.4	123	33.35		T
		02-08-2001	10.4	124	33.04		T
		03-06-2001	10.4	123	31.7		T
		04-09-2001	10.5	124	30.67		T
		05-09-2001	10.6	127	30.14		T
18N/03E-35G01	AFC091	04-18-1991	-	-	13.7		R
		05-04-2000	-	-	14.53		T
		05-25-2000	-	-	14.75		T
		06-28-2000	-	-	15.74		T
		07-26-2000	11.6	127	15.42		T
		08-30-2000	12.4	126	15.8		T
		09-28-2000	11.3	126	16.01		T
		10-26-2000	10.3	125	15.66		T
		11-29-2000	8.8	125	15.24		T
		01-09-2001	8.6	124	14.78		T
		02-08-2001	8	125	14.78		T
		03-06-2001	9.7	125	15.16		T
		04-09-2001	9.7	125	14.62		T
		05-09-2001	10.1	128	14.88		T
18N/03E-25P01	AFC092	02-12-1980	-	-	17.5		R
		05-04-2000	-	-	19.5		T
		05-25-2000	-	-	19.98		T
		06-28-2000	-	122	22.26		T
		07-26-2000	12.3	116	23.72		T
		08-30-2000	12.4	144	24.74		T
		09-19-2000	-	-	24.72		T
		09-28-2000	11.5	133	24.52		T
		10-26-2000	11.5	130	23.55		T
		11-29-2000	11.4	134	21.6		T
		01-09-2001	11.2	142	20.3		T
		02-08-2001	11.2	133	20.25		T

Appendix H - Summary of groundwater levels, temperature, and specific conductance for monthly observation wells within the Muck Creek watershed

Local Number	Well Tag Number	Sample Date	Temperature (Deg C)	Specific Conductance (us/cm@25C)	Water Level (feet) [1]	Water Level Status [2]	Water Level Method [3]
		03-06-2001	11	129	19.16		T
		04-09-2001	11.3	134	18.64		T
		05-09-2001	11.5	133	18.66		T
		06-25-2001	-	-	19.83		T
18N/04E-29E01	AFC093	11-21-1983	-	-	1.65		R
		05-25-2000	-	-	3.5		S
		06-28-2000	-	180	4.21		S
		07-26-2000	12.3	179	4.61		S
		08-30-2000	12.2	180	4.47		T
		09-28-2000	12.3	181	3.98		T
		10-26-2000	11.2	182	3.04		T
		11-29-2000	11.2	181	3.08		T
		01-09-2001	10.7	179	2.64		T
		02-08-2001	9.1	180	2.46	R	T
		03-06-2001	9.8	179	3.29		T
		04-09-2001	10.4	182	1.94		T
		05-09-2001	10.7	183	2.21		T
18N/04E-14C01	AFC094	02-04-2000	-	-	51.42		T
		02-22-2000	-	-	51.17		T
		03-23-2000	-	-	50.42		T
		04-26-2000	-	-	51.21		T
		05-25-2000	-	-	51.73		T
		06-28-2000	-	-	52.72		T
		07-26-2000	-	-	53.58		T
		08-30-2000	-	-	54.85		T
		09-28-2000	-	-	55.67		T
		10-26-2000	-	-	56.3		T
		11-29-2000	-	-	56.76		T
		01-09-2001	-	-	56.64		T
		02-08-2001	-	-	56.57		T
		03-06-2001	-	-	56.58		T
		04-09-2001	-	-	56.28		T
		05-09-2001	-	-	55.13		T
18N/04E-36K01	AFC095	09-12-1985	-	-	5.9		R
		04-18-2000	-	-	-1.1	F	T
		05-25-2000	-	-	-0.96		T
		06-28-2000	-	-	-0.05		T
		07-26-2000	-	-	1.9		T
		08-30-2000	-	-	4.89		T
		09-28-2000	-	-	4.9		T
		10-26-2000	-	-	1.38		T
		11-29-2000	-	-	-0.92		T
		01-09-2001	-	-	-1.1	F	T

Appendix H - Summary of groundwater levels, temperature, and specific conductance for monthly observation wells within the Muck Creek watershed

Local Number	Well Tag Number	Sample Date	Temperature (Deg C)	Specific Conductance (us/cm@25C)	Water Level (feet) [1]	Water Level Status [2]	Water Level Method [3]
		02-08-2001	-	-	-1.1	F	T
		03-06-2001	-	-	-1.25	F	M
		04-09-2001	8.3	153	-1.35	F	M
		05-09-2001	9	154	-1.28	F	M
17N/04E-02M01	AFC096	08-11-1992	-	-	34.2		R
		04-19-2000	-	-	-0.8	F	T
		05-25-2000	-	-	14.2	R	T
		06-28-2000	-	186	8.87		T
		07-26-2000	-	-	19.11	R	T
		08-30-2000	13.7	188	24.77	R	T
		09-28-2000	10.3	180	-		
		10-26-2000	-	177	4.89		T
		11-29-2000	9.4	176	3.27	R	T
		01-09-2001	9.3	176	0.65		T
		02-08-2001	-	177	-0.29		T
		03-06-2001	8.9	176	-0.78		T
		04-09-2001	9.3	178	-0.8	F	T
		05-09-2001	10.4	180	4.59		T
17N/04E-02M02	AFC097	11-09-1990	-	-	21.4		R
		05-25-2000	-	-	18.4		T
		06-28-2000	-	-	28.4	R	T
		07-26-2000	-	-	41.36	R	T
		08-30-2000	-	-	42.87	R	T
		09-28-2000	-	-	28.68	R	T
		10-26-2000	-	-	12.22	R	T
		11-29-2000	-	-	8.1		T
		01-09-2001	-	-	6.73		T
		02-08-2001	-	-	6.55		T
		03-06-2001	-	-	4.71		T
		04-09-2001	-	-	4.95		T
		05-09-2001	-	-	6.63		T
18N/04E-30H01	AFC098	03-23-2000	-	-	7.89		T
		04-26-2000	-	-	9.54		T
		05-24-2000	-	-	9.87		T
		06-28-2000	-	135	10.38		T
		07-26-2000	12.1	133	10.76		T
		08-30-2000	13.1	135	10.71		T
		09-28-2000	12.1	134	10.84		T
		10-26-2000	11.2	137	10.27		T
		11-29-2000	9.4	135	9.79		T
		01-09-2001	8.6	136	9.59		T
		02-08-2001	8	136	9.7		T
		03-06-2001	8.3	138	10.03		T

Appendix H - Summary of groundwater levels, temperature, and specific conductance for monthly observation wells within the Muck Creek watershed

Local Number	Well Tag Number	Sample Date	Temperature (Deg C)	Specific Conductance (us/cm@25C)	Water Level (feet) [1]	Water Level Status [2]	Water Level Method [3]
		04-09-2001	8.5	140	9.35		T
		05-09-2001	9.3	148	9.54		T

[1] Water level: The reported values refers to the depth to water, in feet, below land surface

[2] Water level status:
F - the well was flowing at the time of measurement
R - the well was recently pumped, the water level was slowly recovering

[3] Water level method:
M - water level measured with a manometer
R - water level reported by driller, measurement method not specified
S - water level measured with a steel tape
T - water level measured with an electric tape